Ericsson
REVIEW
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Cover: Expander tool. Any investment in new infrastructure is costly, but investments in regions where average user income is low are associated with greater risk. Ericsson's cost-effective Expander solutions for GSM and CDMA have been designed to reduce this risk for operators who want to pursue business opportunities in new-growth markets, such as remote and rural regions and the emerging markets of developing nations.

Ericsson
REVIEW

THE TELECOMMUNICATIONS TECHNOLOGY JOURNAL

The purpose of Ericsson Review is to report on the research, development and production achievements made in telecommunications technology at Ericsson. The journal is distributed to readers in more than 130 countries.

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Contributors

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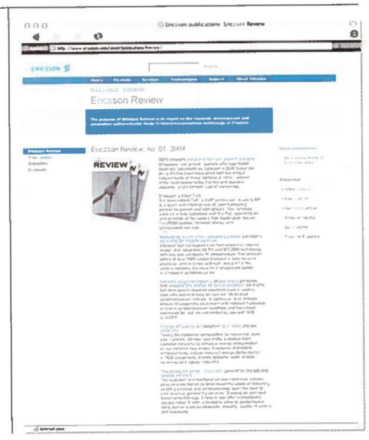


Editorial

I wasn't there, so I might never know for certain what was discussed when SMS grew out of being an idea into a full-fledged service. Nor do I know what kind of expectations were put on it when SMS was first launched. I would assume, however, that anybody with an interest in radio or wireless communications would have thought it a fascinating notion. But massive appeal? Who would've guessed? It is certainly exciting to see how SMS has developed, and I can't help but wonder what new, unforeseen applications it can or will yet be used with.

Ericsson Instant Talk—Ericsson's push-to-talk solution for ordinary consumers/subscribers—might well be the next "SMS". Its initial application and allure are substantial enough, but here we also have a potential springboard for numerous other promising services. Time will tell, but this is my gut feeling.

Telecommunication is fun, and I am sure that we have barely even seen the beginning. That is part of the appeal of being in this business. Consequently, I had to smile when I read recently about an order from fixed network operator Telefónica de España for fixed cellular terminals (FCT) based on the GSM standard. "Besides voice and fax," the article said, "users must also be able to use the Internet, enjoying the same performance as from fixed telephony." What you can't know without having seen the article is that the solution introduces modern telephony to rural parts of Spain. So now even the rural population can benefit from modern communication!

Earlier this year, Ericsson also announced its Expander program, which has been developed especially to help operators to tap into new-growth markets—for example, rural areas and developing countries where the majority of the population is made up of low-income subscribers. Finally, a viable business case for taking modern telecommunications services to the rest of the world!

In this issue of *Ericsson Review*, you can read about Ericsson Instant Talk and Ericsson's Expander program for GSM (the entire Expander program comprises GSM and CDMA). You can also read about

- the Mobile Packet Backbone Network (Mobile-PBN), which is a verified reference network design that optimally integrates GPRS and WCDMA with site and backbone IP infrastructure;
- stand-alone products that support the design of synchronization networks—network synchronization is also part of the Mobile-PBN offering;
- energy efficiency enhancements in radio access networks—Ericsson has thoroughly assessed the life cycles of its systems to see where and how it can reduce operating costs and impact on the environment. This, in turn, has led to several product enhancements, in particular, in radio access networks, where energy consumption is greatest; and
- Ericsson's Public Ethernet solution, which has been developed using standard Ethernet technology and incorporates the reliability, quality of service, security and manageability necessary for a public telecommunications network.

In short, this issue of *Ericsson Review* presents a nice balance of relevant and timely articles. Enjoy!

Eric Peterson
Editor

GSM network solutions for new-growth markets

Michael Bjärhov and Christer Friberg

The global number of mobile subscriptions is predicted to grow from 1.3 billion as of January 1, 2004 to more than 2.2 billion by the end 2008. Most of this growth will occur in emerging new-growth markets, which will drive penetration among the low-spending subscriber segment.

Two key technologies will cater for this subscriber growth: GSM (and its evolution to WCDMA) and CDMA. This focus of this article is on GSM technology, which has been deployed in every major market except Japan and Korea, has a strong market position with extensive availability of low-cost mobile terminals, and has an evolution path to increased capacity and faster data services.

The emphasis in new-growth markets is on increasing subscriber penetration, in particular, the segment of population which could not previously afford mobile telephony services or which lived outside of areas with mobile coverage.

Subscriber penetration in many "mature" markets is now saturated. So instead of focusing on growth in these markets, the main emphasis is on increasing revenue per subscriber by introducing advanced features and services.

This article describes the operator challenges and gives an in-depth description of how Ericsson's Expander Radio Coverage solutions can support operators when expanding into new, untapped markets.

Market characteristics

New-growth markets have several common characteristics: cost of capital is high, and a generally low gross domestic product (GDP) implies a high potential base of low-income customers. Despite government efforts to create sustainable rural cities, population growth in these markets is primarily concentrated to mega-cities.

Because the new-growth markets are cash economies, the most prevalent type of mobile subscription is prepaid. Some markets have only recently been deregulated, which means basic utilities and communications infrastructures are often lacking or based on aging technology. In some cases, the users have no previous experience of telephony. However, this does not mean that they are satisfied using dated technical solutions when services are introduced.

Analysts predict that the number of mobile subscribers in these markets will double between 2004 and 2008. Likewise, mobile traffic, they say, will more than double over the same period. Tariffs in these markets are often high, which leads to low penetration with relatively high average revenue per user (ARPU). In most markets, however, competition—often in combination with number portability—will drive tariffs down. Statistics show that thanks to the related subscriber growth, operators can maintain or even increase profitability as tariffs fall. One of the most important enablers of growth is the availability of low-cost terminals.

Today's operators have an opportunity to tap into this potential by deploying cost-effective coverage and capacity solutions. By adopting future-proof technology, they will also be able to meet the evolving demands of new subscribers. Existing operators, with established footprint and networks, are best positioned to acquire new subscribers. They can spread their costs and draw on economies of scope and scale. Although the current focus is on subscriber growth, these new subscribers also represent growing per-customer traffic and spending—after all, today's new users are the advanced users of tomorrow.

BOX A, TERMS AND ABBREVIATIONS

BSS	Base station subsystem	OL	Overlay
CAPEX	Capital expenditure	OPEX	Operating expenditure
CDMA	Cell-division multiple access	OSS-RC	Operations support system—radio and core
CDU	Combining and distribution unit	RAN	Radio access network
dTRU	Double TRU	RBS	Radio base station
EDGE	Enhanced data rates for global evolution	RX	Receiver
GDP	Gross domestic product	SMS	Short message service
GPRS	General packet radio service	TCC	Transmitter coherent combining
GSM	Global solution for mobile communications	TRU	Transceiver unit
KPI	Key performance indicator	TRX	Transceiver
MTBF	Mean time between failures	UL	Underlay
O&M	Operation and maintenance	WCDMA	Wideband CDMA

Operator challenges

Operators face several challenges in addressing new-growth markets. These challenges affect every area of operations and include business-, network-, and capital-related expenditures.

Subscriber acquisition

A substantial part of business operations focuses on signing up new subscribers. And perhaps the biggest obstacle is a lack of low-cost terminals. Another challenge in some markets is the perception that mobile phones are a luxury item—indeed, some countries apply luxury tax to mobile phones, which further inflates prices.

Charging and managing credit risk

Obviously, to generate revenues and positive margins, operators must be able to manage credit risk and prevent revenue leakage. Also, to compensate for expected low revenues per customer, they must have large volumes of subscribers. In practice, this means prepaid services for the vast majority of users, and a real-time charging system to prevent credit overruns. To minimize churn, operators must also consider what level of prepaid card denomination best encourages users to refill and retain their subscriptions. User spending control is also important, because it is doubtful that users can deal with unexpectedly large bills at the end of the month.

Distribution channels

Giving people convenient and simple ways of refilling their subscriptions is essential. High-cost refills and a lack of dealers and refill channels are barriers to usage. Starter packs should be promoted and made available through many channels. This is more easily accomplished with prepaid or hybrid packages than with post-paid subscriptions. Prepaid offerings are easier to distribute, sign up and activate because they do not necessitate contracts or credit checks.

Service differentiation

Service differentiation, which is about providing the right services to the right segments, plays a vital role in attracting first-time users and profitably addressing new subscriber segments with lower spending levels. The service mix can be used as a differentiating factor, but the services themselves must never skimp on quality. Operators who use voice quality and grade of service as differentiators risk greater churn.

Radio network infrastructure

Many new-growth markets face two fundamental network-related challenges. These are a lack of radio coverage in rural areas, and the need for greater capacity in densely populated areas. Other challenges arising from serving a low-income customer base include lack of financing for new technology, and excessive competition, which erodes profit margins. The challenge is to adjust the cost structure needed to acquire necessary features and functionality while remaining profitable at subscriber spending levels of less than USD 5 per month. This means low production cost per minute of use (MoU) and high utilization of network resources. Network equipment typically accounts for the largest share of capital expenditures (CAPEX)—some 50 to 80 percent of a mobile operator's CAPEX is network-related. For operators in new-growth markets, radio access makes up the biggest part of investments in network infrastructure.

There are, however, many interdependencies between operating expenditures (OPEX) and capital expenditures, and in some cases it is possible to reduce OPEX through capital investments. Investing in better-quality base station equipment and flexible base station subsystem (BSS) features, for example, can give better coverage and reduce the total number of sites. Reducing the base station footprint can help cut site rental costs; more advanced base stations can reduce power consumption[1]; and improved in-service performance can result in fewer site visits.

Transmission flexibility

Most new-growth market subscribers reside in large cities where greater capacity is the primary issue. In rural areas, however, the need is not for capacity but rather for transmission and radio coverage. New network architecture and equipment packages are thus needed to deliver cost-effective coverage quickly. The cost of building a transmission network usually accounts for half of the total network investment. Therefore, it often pays to lease transmission during the first years of operation.

Network complexity

Many operators who are targeting new-growth markets will have to recruit or train personnel to run their networks. Existing operators might already have advanced networks based on dual-band, general packet radio service (GPRS) and service networks that offer a competitive portfolio of services. But they will still need to enhance traffic capacity in urban areas and plan and build out coverage in new regions. To reach the full potential of traffic capacity from existing infrastructure (radio sites and available spectrum), they will need advanced radio features, and they might need help implementing them. Unless operators are able to reuse existing radio sites, the only way forward will be to obtain more spectrum or to increase radio network density by adding more and smaller sites. For many operators, however, these options are not feasible. Instead, they need strong sets of advanced features and built-in system functionality to help guide personnel when planning and running their networks.

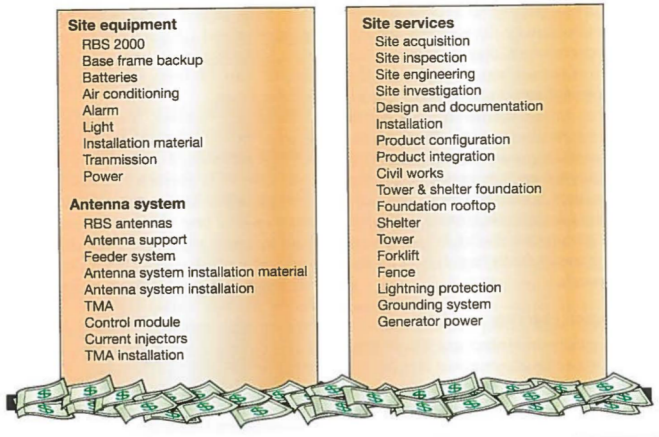


Figure 1
Examples of CAPEX items for an RBS site.

The deployment of traffic in new areas is often related to the placement of radio sites in remote areas. Some sites can only be accessed through many days of hard traveling. Obviously, this is undesirable. Operators thus want to reduce the number of sites needed to provide coverage. They also want more reliable equipment. Finally, they want radio sites that are easy to understand and work on. That way, less technically qualified personnel can, if necessary, be sent to sites to perform simple tasks.

In addition to network expansions, which increase network complexity, wireless data infrastructure will become more important for new-growth markets—in particular because GPRS-based services open the door to significantly lower voice tariffs. Ericsson Instant Talk services, which will enable affordable group voice communication, will likely be as successful in these new markets as short message service (SMS).[2] The infrastructure will be based on GPRS, which heightens the requirements for planning and running wireless end-to-end data services.

Network rollout and tuning

A lack of skilled labor is often a limiting factor when operators want rapid rollout. Notwithstanding, to achieve maximum capacity and coverage on a limited budget, operators must pay careful attention to radio network tuning. By hiring in experienced crews, they can substantially shorten this slow and tedious process.

Advanced radio network functions that facilitate radio network planning and improve network performance are also important parts of the process. For example, four-way receiver diversity greatly increases sensitivity in base station uplinks, thus improving coverage characteristics. Similarly, advanced analysis and reporting functions available via the operations support system—radio and core (OSS-RC) present network information in a format that is easily understood by operation and maintenance (O&M) staff.

Radio site solutions

Standard site configurations are often used to simplify network rollout. The sites can be assembled in a factory environment or on site. In either case, efficient supply flow is needed to deliver all necessary materials on time. Given the cost structure of new-growth markets, the most cost-effective way of building a site generally makes use of local suppliers and certified local subcontractors.

Managed services

Many operators in new-growth markets have limited experience of handling mobile network management and growth. They might therefore benefit from different kinds of managed services. This could be limited to hosting complex nodes—for example, for MMS—but, for good reason, there is a growing trend to outsource entire network operations.

The ultimate outsourcing model—where a supplier delivers capacity as specified by a number of key performance indicators (KPI)—is now taking form in some markets. Here, the network is built out at a pace determined by actual traffic growth. The model addresses financing and competence, and is likely to grow in importance in coming years. It also allows operators to focus on their core business, which is to deliver competitive subscriber services.

Low-cost radio networks for rural coverage

Different solutions for different segments

The main objective of running a telecommunications business is to make money. Consequently, when it comes to service offerings, it frequently pays to stay ahead of local competition. Most markets have more than one mobile operator, and because the majority of users have prepaid subscriptions it is usually quite easy for them to switch operators. New subscribers generally fall into two segments: those who reside in

- urban and suburban areas, where coverage is already in place. The challenge to add more subscribers is often limited by available radio spectrum. The GSM radio networks in this segment are *interference-limited*; and
- rural areas, where traffic demand is unknown because coverage does not currently exist. Operators must thus take commercial risk, investing in infrastructure without knowing when it will pay off. The GSM radio networks in this segment are *coverage-limited*.

The radio features of Ericsson's advanced base station subsystem (BSS) offer a solution for the former segment—that is, the segment with interference-limited systems. Getting more traffic into limited radio spectrum requires sophisticated functions enabled by a rich portfolio of advanced radio features and solutions that allow more carriers (transceivers, TRX) to be inserted into radio networks without jeopardizing the perceived radio quality.

Available solutions for gaining more capacity through cell-, network-, and channel-capacity solutions were described in Ericsson's GSM RAN capacity solutions.[3] Ericsson leads the industry when it comes to solutions for optimizing the use of capacity in existing spectrum.

Smaller cities, villages, and sparsely populated areas make up the rural-area segment, which requires efficient radio solutions with a minimum of radio base station (RBS) sites. A common fallacy is that to minimize the risk of business investments in rural areas, operators should only consider low-priced equipment.

Cost structure of the RAN

Network equipment typically accounts for the largest share of capital expenditures. About 50 to 80% of a mobile operator's capital expenditures is related to networks. For most operators, radio access takes the lion's share of the infrastructure budget. The cost structure of the radio access network (RAN) is usually divided into

- CAPEX, which covers all costs related to initial investments; and
- OPEX, which covers the annual cost of running the network.

The CAPEX for a typical RBS site consists of many elements. The costs associated with an RBS are just part of the total cost that an operator must pay for a new site installation (Figure 1). The price of RBS equipment is only a fraction of the total site cost. But many operators do not readily see that in addition to equipment they will have to pay for services and work carried out by their own organizations or outside help.

Local market conditions affect the actual price of site materials and services. When considering the total cost of infrastructure investments, most expenditures relate to radio network infrastructure. Breaking this down in greater detail, we see that the actual cost of the RBS is only about one-third of the total investment in infrastructure—indeed, most expenditures relate to site materials and services (Figure 2).

Operating expenditures are another large financial item that covers all the costs of operating RBS sites in networks. Many costs are easy to forecast because they are based on givens such as set prices for energy and power, transmission, and site rental. Operating expenditures also include maintenance costs relating to

- manual intervention at sites (for example, replacing batteries, adjusting air condi-

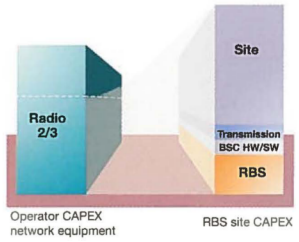


Figure 2
Cost structure for operator's infrastructures.

tioners, and eliminating transmission failures); and
- unplanned site visits to correct faulty equipment—this expense is hard to nail down because visits can involve salaried employees, travel time, and equipment (car rental and spare parts).

It goes without saying that better, more reliable RBS equipment reduces these costs.

Fulfilling customer demands for lower OPEX

Ericsson knows that its customers want more robust RBS equipment. Therefore, it has developed the second generation of the RBS 2000 family. In doing so, Ericsson reduced the number of replaceable units by 50% while maintaining reliability per unit. These enhancements were made possible thanks to a new hardware platform that facilitates greater integration. The most important element in this new platform is the double transceiver unit (dTRU) that is a transceiver unit which contains two complete GSM transceivers.

Reliability measurements

The most advanced unit inside an RBS is the transceiver. It contains
- powerful amplifiers for transmitting strong radio signals;
- sophisticated processing capability for radio reception; and
- advanced features for handling traffic.

Using a high degree of integration, Ericsson has been able to maintain the same level of reliability from its dTRU as from the previous TRU (with one TRX).

The main objective of the design was to improve the reliability of RBS configurations. To determine how the number of units affects the service levels (reliability) of a large population, Ericsson compared the reliability of systems built with different types of units with the same MTBF value. Figure 3 compares two TRXs in a replaceable dTRU and one TRX in a replaceable dTRU.

Most operators have several RBS installations in their network. Assuming that every reported fault on the radio must be treated immediately, it is easy to see the advantages of having more reliable products in the field. Figure 4 illustrates the potential savings of using more robust radio equipment for medium-sized configurations.

The best ways of achieving cost-effective deployment of a radio network are to reduce the number of required sites and to invest in RBSs that require less maintenance. In some situations it might be beneficial to employ low-capacity RBS solutions, for example, where the terrain prevents the deployment of large radio cells or where the demand for capacity is low and is not expected to change in the near future. Through its Expander program, Ericsson has introduced new capabilities for existing RBS models and new RBS models that better meet operator deployment strategies. The same hardware platform has been used in each model. To the operator, this translates into reduced OPEX (more reliable RBS equipment) and reduced CAPEX (fewer sites and fewer spare parts).

Solutions for fewer RBS sites

The best route for deploying RBSs in new areas where traffic demand is unknown is to deploy thin but continuous radio coverage via high-performance radio. With two TRXs in each dTRU, the new architecture of the RBS 2000 facilitates additional enhancements to radio performance. Note: When planning a radio network that uses dTRUs, operators should consider the RBS
- downlink capabilities—for reaching the phone; and
- uplink capabilities—for receiving weak signals from the phone.

Three downlink enablers

The dTRU contains two TRXs and an internal hybrid combiner that combines the transmitter signals from the TRXs. The TRXs thus share a common outlet that is fed to the combiner and antenna system. This solution supports four TRXs per antenna.

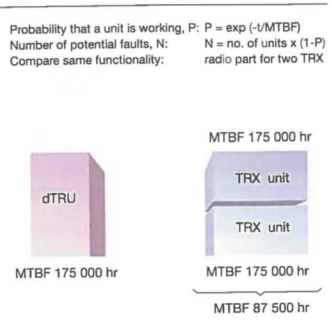

Probability that a unit is working, P: P = exp (-t/MTBF)
Number of potential faults, N: N = no. of units x (1-P)
Compare same functionality: radio part for two TRX
dTRU
MTBF 175 000 hr
MTBF 175 000 hr
TRX unit
TRX unit
MTBF 175 000 hr
MTBF 87 500 hr

Figure 3
MTBF reduction when number of units is increased.

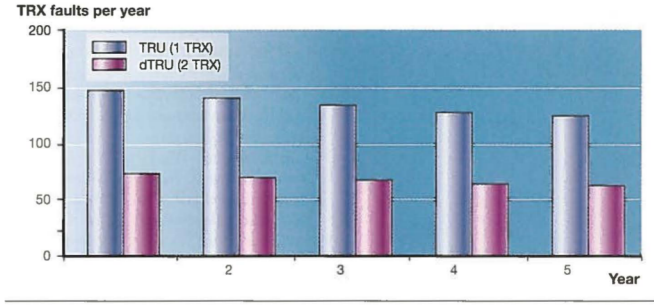


Figure 4
Reliable hardware reduces the number of site visits. This example reflects an installed base of 500 RBSs with six TRXs in each cabinet.

If greater output power is preferred—for example, to provide greater coverage—each TRX can instead be connected directly to the combining and distribution unit (CDU) for connection to the antenna system. This limits the number of TRXs that can be installed in a cabinet, due to the fixed number of inlets to the CDU (if the internal hybrid in the dTRU is not used, only one TRX can be used per CDU inlet). This solution provides greater output power and enables operators to build larger cell areas, which cuts down on the number of RBS sites needed to cover a specific region.

Transmitter coherent combining (TCC) is a software solution that improves the downlink. The solution combines intelligent use of phase adjustment with the internal hybrid combiner (Figure 5). When the dTRU runs in TCC mode, it continues to operate in its normal environment—that is, it does not generate extra heat that might affect the reliability of the dTRU or other equipment in the cabinet.

The three downlink enablers mentioned above use the same equipment or dTRU. The only significant difference is the way in which the transmitter (TX) cables are attached when the internal hybrid combiner in the dTRU is not used. Ericsson also offers a fourth option (available since 1997) for enhancing the downlink. The software power boost function supports downlink transmitter diversity (the mobile phone combines the best of two signals) by transmitting the same information on two TRXs with a short delay and different antennas. Compared with TCC, transmit diversity has

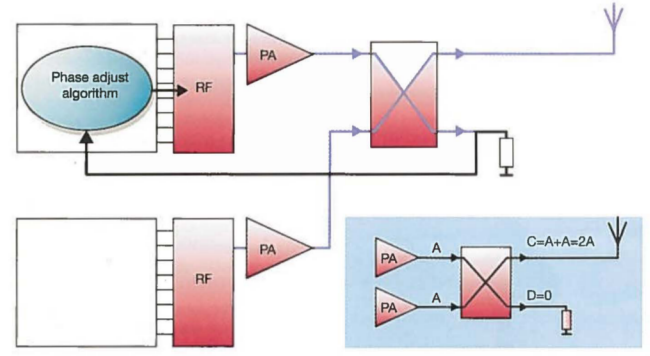


Figure 5
The TCC concept.

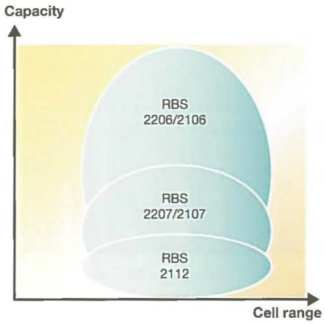


Figure 6
Macro RBS enhancements to meet operator requirements for investing in low-traffic areas. New radio capabilities (TCC, 4-RX diversity, and smart range configurations) reduce the number of radio sites. Likewise, the addition of new outdoor RBS products—RBS 2107 (6 TRXs) and RBS 2112 (2 TRXs)— gives operators greater flexibility.

some negative implications when the mobile phone must decode eight phase shift keying (8-PSK) modulation for EDGE. Likewise, terrain-dependent conditions reduce the certainty of cell coverage.

In summary, in terms of coverage and greater data throughput with EDGE, TCC is preferred over transmit diversity for enhancing the downlink. Box B and Figure 6 summarize the recommended options that make use of the latest hardware platform.

One other important factor to consider when planning a balanced system is the uplink. The uplink capability is more difficult to measure and verify. This is because the measurement requires sophisticated testing that can only be carried out in laboratory environments.

Ericsson's new hardware platform offers some significant improvements in signal reception from mobile phones—for example, improved control over the receiver path in the chain from antenna to extracted signal.

Besides improved receiver path, operators benefit from additional power for processing a more advanced diversity algorithm—given the availability of the new algorithm and platform, Ericsson recommends that operators use a greater value for diversity gain. Operators may also use all four RX branches in one dTRU to improve the uplink from a single source—this is called four-branch diversity. Regular two-branch diversity can yield an additional 4 to 5 dB in gain. By comparison, depending on how the antennas are arranged, four-branch diversity can yield an additional 7 to 9 dB in gain.

Ericsson provides values for normal network conditions and guarantees the values for radio channels that represent real conditions. Different dynamic channels, or faded channels, are used to communicate real performance values. If static values are to be used, the values can be enhanced by an additional 1-2 dB. Ericsson wants to provide operators with accurate values that can be used when planning radio networks. This is why Ericsson provides dynamic, fading-model values.

Good receiver capability cannot be underestimated. At present, many handsets are designed to have the lowest possible output power. This results in longer standby time, which is an attractive feature to end-users. Notwithstanding, it puts even greater demands on the uplink—for reaching a balanced-link budget and guaranteeing coverage in the radio cell. To achieve good radio quality, which is a prerequisite for offering good subscriber services, operators would thus be wise to consider the mobile phone population in their networks. Figure 8 summarizes the different uplink enablers.

The dTRU is very flexible and can be used for several purposes (Figure 9). Its two TRXs, for instance, can be used separately or, by combining Ericsson's unique TCC to improve the downlink and four-way diversity to improve the uplink, they can be configured to create a "super TRX".

Flexible configurations

The downlink- and uplink-enabler solutions can be combined in the same cabinet to offer very attractive combinations of solutions for broad coverage (strong downlink) and high capacity (many TRXs per cell). Ericsson's RBS 2206 (indoor) and RBS 2106 (outdoor) cabinets contain six dTRUs per cabinet.

Having the same equipment in different versions of the RBS gives operators greater flexibility in finding and applying the most

BOX B, COVERAGE ENABLERS

DOWNLINK ENABLERS

Same dTRU can be used in different configurations

Combined mode (internal hybrid in dTRU)	42.0 dBm
Uncombined mode	45.5 dBm
Transmitter coherent combining (TCC)	48.0 dBm

Transmitter diversity (software power boost, SWPB)

Not recommended for extending cell range due to environmental dependencies at cell border
EDGE (8-PSK) performs worse with TX diversity than with TCC

UPLINK ENABLERS

Receiver sensitivity without TMA	-111.0 dBm
Receiver sensitivity with TMA (+compensation for feeder loss)	-111.5 dBm
Two-branch RX-diversity, urban/suburban	4.5 dB
Two-branch RX-diversity, rural	3.5 dB
Four-branch RX-diversity	7-9 dB

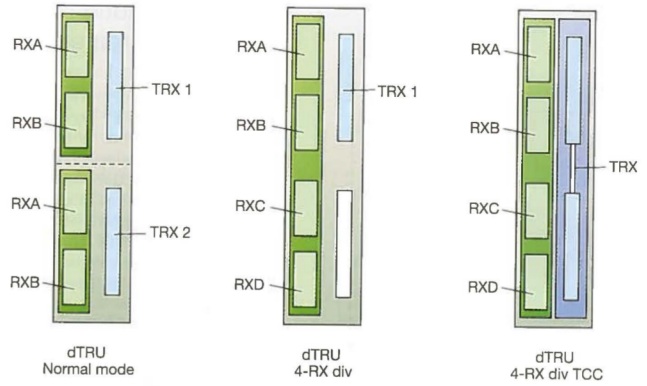


Figure 7
One dTRU can easily be used to extend coverage.

appropriate configuration. For example, a common configuration might have four TRXs per cell (4+4+4 configuration). Six dTRUs are configured using the internal hybrid in the dTRU. The configuration is also called *capacity mode*, because emphasis is on providing as many TRXs as possible per antenna.

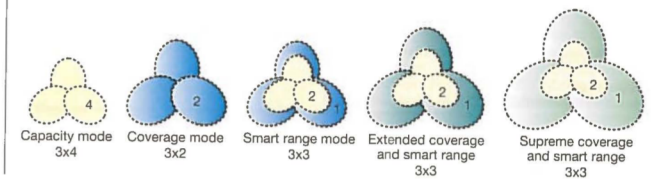
One other configuration, 2+2+2 or *coverage mode*, yields greater output power by not using the internal hybrid in the dTRU. The CDU inlet solely permits three dTRUs to be inserted in the cabinet.

By combining dTRUs configured both with and without the internal combiner, operators can obtain a combined capacity mode and coverage mode configuration in the same cell. This configuration retains the coverage provided by high-output-power TRXs and adds extra capacity by using two additional TRXs with lower output power. A traffic-steering feature manages the differences in the cell range by moving end-users to the smaller overlay subcell when appropriate. This frees up capacity in the larger underlay subcell, which, in turn, yields a total of three TRXs per cell. What is more, the 3+3+3 configuration fits in one RBS cabinet. This approach of combining different output power in the same cell is called the *smart range configuration*.

By boosting the cell range of the underlay subcell, operators can also share the combination of larger subcells (greater coverage) and smaller subcells (greater capacity) with other mechanisms for enhancing coverage. They can also use TCC and run one dTRU as a more powerful TRX. In this case, the same set of cabling is used as for the capacity-mode configuration. The capability is activated with a software command from the BSS. Because the downlink has been extended, this solution gives greater coverage—*extended coverage mode*—than the coverage-mode configuration.

Even better coverage can be obtained when the dTRU is run in combination with the TCC concept and advanced, four-branch-receiver diversity in the uplink. This combination is called *supreme coverage mode*, because the combination offers outstanding radio coverage performance. Figure 11 summarizes the configurations that can be provided in one cabinet.

Figure 8
Example of flexibility provided by the RBS 2x06.



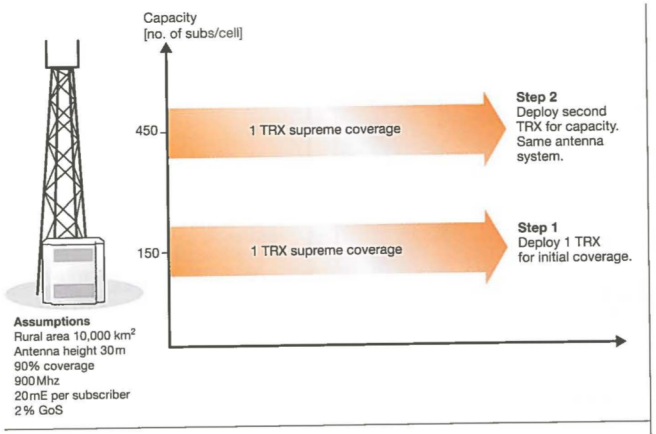


Figure 9
Initial deployment with one TRX per cell and expanded to two TRXs per cell.

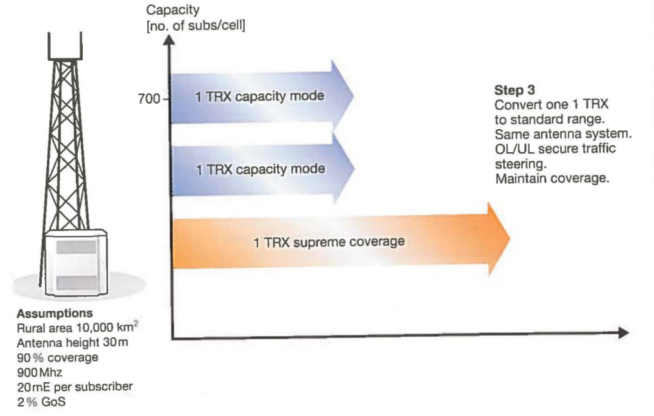


Figure 10
Third stage of capacity expansion.

Entry-level solution with potential for greater capacity

Below follows a scenario in which an operator begins deploying large, limited-capacity cells. Later, when traffic increases, more capacity can be added. The sequence (Steps 1-4, Figures 9-11) shows how an initial, extreme-coverage site is expanded to yield ten times as much capacity per cell through the addition of TRX hardware and BSS software features. By employing different configurations of the same set of RBS equipment, Ericsson can help operators to continually optimize their radio networks using a minimum of sites. If conditions are right, large areas can be covered using a single RBS.

Step 1

Ericsson's unique dTRU can be configured as a single TRX with double output power. This reduces the initial investment while providing maximum coverage from a minimum of sites. The solution can be further enhanced with four-RX diversity in the uplink.

Step 2

Capacity is enhanced by inserting an additional dTRU per cell—doing so almost triples the capacity for serving regular subscribers. The antenna and feeder system need not be upgraded (Figure 9).

Step 3

Capacity can be further enhanced without a visit to the site: from the operations center, the second dTRU is put into the capacity-mode configuration, making three TRXs available per cell. Capacity is now up to five times that of the initial configuration. Additional BSS features—dynamic overload (OL) and underload (UL)—are also introduced to secure traffic routing between two subcells with different coverage (Figure 10).

Step 4

Once again, capacity can be increased without a visit to the site. After completing this step, capacity will be 10 times that of the initial configuration. Ericsson's unique, load-based, dynamic half-rate function allocates traffic channels at operator-defined thresholds. The function enables two users to share a single available radio channel in the same cell. If necessary—for instance, during peak hours—every connection might make use of the half-rate function (Figure 11).

When traffic demand skyrockets, operators can either add

- macro RBS capacity, by deploying additional RBS cabinets at each site and synchronizing them with existing cabinets; or
- micro RBS capacity to offload cells, by introducing micro cells in macro cells.

When this decision comes, however, it will be based on steady traffic demands in the region. That is, the operator is no longer faced with having to invest in a region with unknown traffic volumes. All subsequent expansion with new RBS cabinets will thus be based on healthy traffic scenarios. This means it is fairly easy to calculate when the investment will pay off.

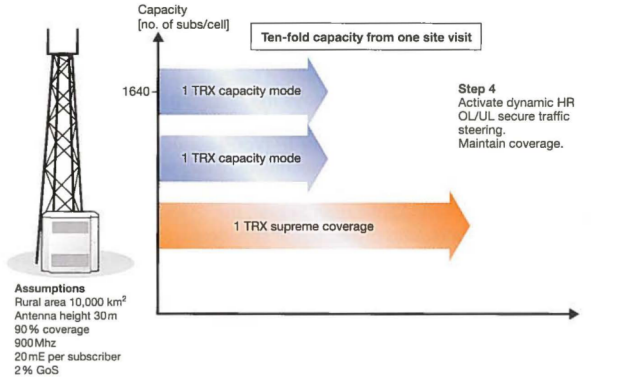


Figure 11
Stage four: Ten-fold capacity per cell in the same RBS cabinet and from the same antenna system.

Conclusion

As-yet untapped new-growth markets offer significant opportunities for growth and expansion provided they are addressed properly. Competition and price pressure in these markets are fierce, marketing costs and churn rates are high, and initially, there will be little demand for value-added services. Typical characteristics of these markets are a low-income subscriber base, limited financing for new technology, and competition-eroding margins. Operator inexperience is also an issue in some areas. Notwithstanding, knowing that new subscriber growth will primarily come from these markets, Ericsson is giving its highest priority to all related requirements.

Ericsson's GSM Expander program, for example, has been developed with these unique requirements in mind. In short, it helps operators to address the challenges of new-growth markets by

- limiting entry-level investments;
- providing flexible and scalable capacity;
- minimizing the total cost of ownership; and
- protecting investments through high-quality technology platforms.

The solutions are reliable and open-ended, which means no compromises are made in performance or quality. Initially, operators might opt to offer a limited amount of services, capacity and functionality, but they are free to expand them later without costly re-engineering.

Ericsson's leadership in the wireless industry maximizes operator business advantages today and provides a secure route toward future capabilities. The Ericsson Expander offering yields different capacity solutions from the same equipment—this lowers operator investment risks, because an RBS and all its parts, for example, are the same regardless of whether they are deployed in urban or suburban areas with heavy traffic or in sparsely populated areas where traffic loads are unknown.

In markets with a large population of prepaid subscribers, competitive operators need to offer the best services in the region. Ericsson's solutions extend cell range without jeopardizing system reliability. No external boosters are needed to improve downlink capability, because operators use the equipment in normal operation mode. This yields better reliability and helps operators to reduce the number of site visits.

To lower business risks, operators need to know that returns on current investments will extend far into the future. Ericsson's large-coverage solution provides a very flexible way of adding capacity as traffic demands increase. This article describes how operators who deploy an RBS site to obtain initial coverage can later boost capacity tenfold through one visit to the site to insert a second dTRU.

Small-capacity macro RBSs are also available as a complement to the portfolio.

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Ericsson Instant Talk

Niclas Medman, Krister Svanbro and Per Synnergren

Push to talk is a quick and informal way of communicating person-to-person and with groups. With a simple push of a button, users can activate voice communication with friends and family—much the same way as using walkie-talkies or private mobile radios. But because it is a mobile communication service, push to talk also enjoys the range and wide area coverage of traditional mobile services.

Ericsson Instant Talk is a voice-over-IP (VoIP) service set up using the session initiation protocol (SIP). The technical realization is based on a total business approach that gives operators a complete solution consisting of the Instant Talk Application Server, the IP Multimedia (IPMM) system, terminal clients, and professional services.

Ericsson's practice of basing products on open standards—to ensure interoperability and rapid uptake of service—also applies to Instant Talk. The solution is fully compliant with the push to talk over cellular (PoC) specification. It has also been built with service evolution in mind, giving operators the ability to add new features and services to enrich the service and the IPMM.

Introduction

Push to talk is the common name for half-duplex voice services activated by pressing a button. PoC is the name of the open specifications for this service. In the consumer segment, push to talk allows users to stay in touch with friends and coordinate leisure activities, such as visits to the cinema or simultaneous communication with a group of family members. In the enterprise segment, it can be used to share information in a group—for instance, a field technician can use it to ask colleagues for help or advice.

Ericsson's Instant Talk solution complies with the PoC specifications. Its users can make person-to-person calls or create an *ad hoc* group call. At present, it is available for implementation in GPRS/EDGE and CDMA2000 networks. WCDMA solutions will follow. PoC and Instant Talk are based on the IP Multimedia System (IMS)—evidence that Ericsson is taking concrete steps toward realizing IP services on IMS in mobile networks.[1,2]

BOX A, TERMS AND ABBREVIATIONS

3GPP	Third-generation Partnership Project
AMR	Adaptive multirate
ASCII	American Standard Code for Information Interchange
AUC	Authentication center
BSS	Base station subsystem
CDMA	Code-division multiple access
CS	Circuit-switched
CSCF	Call/session control function
DNS	Domain name service
EDGE	Enhanced data rates for GSM evolution
EVRC	Enhanced variable rate codec
FTP	File transfer protocol
GLMS	Group list management server
GPRS	General packet radio service
HLR	Home location register
HSS	Home subscriber server
HTTP	Hypertext transfer protocol
IETF	Internet Engineering Task Force
IMS	IP multimedia subsystem
IP	Internet protocol
IPMM	IP Multimedia
IS/IT	Information system/information technology
MRF	Media resource function
OMA	Open Mobile Alliance
PoC	Push to talk over cellular
QoS	Quality of service
RTCP	RTP control protocol
RTP	Real-time transport protocol
SDP	Session description protocol
SIP	Session initiation protocol
UDP	User datagram protocol
UDVM	Universal decompression virtual machine
URI	Uniform resource indicator
WCDMA	Wideband CDMA

SIP-based service

Ericsson Instant Talk is an important step toward making IP-based services an integral part of the mobile service offering and of making the Internet protocol a dominant transport technology for mobile applications. The solution is controlled by SIP, whose philosophy of client-to-client control over multimedia session establishment while drawing on support from servers in the network distinguishes it from other common application layer protocols (FTP, HTTP).[3]

Because SIP can establish, modify and terminate multimedia sessions between two or more clients, it facilitates one-to-many communication, which is a key feature of Instant Talk. Clients use the session description protocol (SDP), contained in the body of SIP messages, to describe what kinds of media they can use and how the media should be transported. End-to-end negotiation of media types and transport permits tandem-free operation—that is, the coded bit stream that contains the talk burst is sent directly to the encoder in the receiving terminal without being decoded in the base station subsystem (BSS). Thanks to SIP end-to-end negotiation, new media coders/decoders (codec) may be introduced in terminals as they become available.

Signaling compression

When designing SIP, the Internet Engineering Task Force (IETF) had the large bandwidth and low latencies of the public Internet in mind, which is to say the size of SIP messages was not a priority. But in the context of mobile environments the size of SIP messages can be a drawback. In mobile systems, radio spectrum is an expensive resource that must be used wisely. Operators must always try to maximize data transport efficiency over the air interface. This problem has been addressed through signaling compression (SigComp), another IETF standard initiated by Ericsson. SigComp is a versatile compression framework that can use any compression algorithm to compress ASCII-based protocols, such as SIP, to a fraction of their original size, reducing both bit rate requirements and transport latency.

SigComp sessions are initialized during the registration phase of the Instant Talk service. The SigComp compressor generates a decompression byte code that contains a preferred compression algorithm and transmits it to the decompressor. The decompressor, called the universal decompression virtual machine (UDVM), decodes the byte code and adopts the decompression algorithm, making it ready to receive compressed SIP messages. Extended operations (an important feature) enable SigComp to learn from SIP messages.[4] Therefore, SigComp becomes increasingly efficient as compression and SIP signaling proceed.

SigComp is a critical component of Ericsson Instant Talk because it can significantly reduce the number of bits sent over the wireless link (compression ratios of 8:1 are not unusual).[5] It greatly reduces the transmission delay of SIP messages, and consequently, the time it takes to establish an Instant Talk session.

Technical realization

Ericsson has taken a total business approach in its technical realization of Intant Talk, providing the infrastructure, terminal clients and professional services, and ensuring availability of terminals. Guided by this approach, Ericsson will continue to optimize performance by implementing enhancements in the radio access network, mobile core network, application servers and clients. Ericsson's ability and willingness to influence the nodes in the end-to-end path of telecommunications systems set it apart from other vendors of push to talk solutions. The commercial launch of Ericsson Instant Talk will include vertical service assurance.

One more important factor is that Ericsson bases its products on open standards. Therefore, handset interoperability will not be an issue. Operators and end-users will be able to choose terminals and terminal vendors freely.

Instant Talk consists of three main parts: the IPMM, the Instant Talk application server, and the handset client.

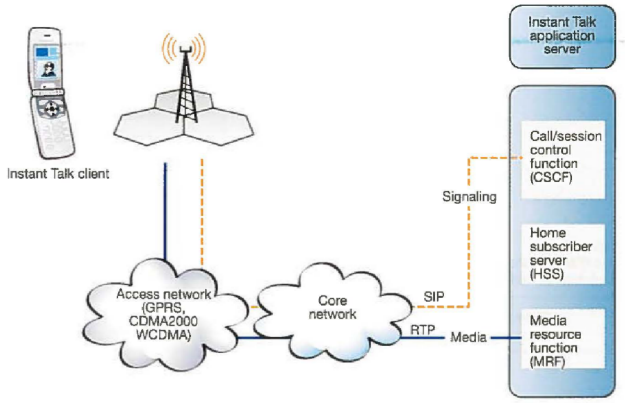

Figure 1
Ericsson Instant Talk high-level architecture.

IP multimedia system

Figure 1 shows a schematic drawing of the nodes involved in the Instant Talk service. At the heart of the solution is the Ericsson IPMM system (Figure 2), which complies with the principles of the IMS standard (3GPP) that was drafted to bring SIP-based communications to the wireless market.[2] The IMS can be deemed a "new" domain that has been added to the mobile core network to support a wide range of SIP-based applications, such as Instant Talk, instant messaging, and presence services.

The IPMM architecture includes the call/session control function (CSCF), the media resource function (MRF), and the home subscriber server (HSS). The CSCF is the teminal's first point of contact in the IPMM domain. All SIP signaling is routed through the CSCF, which also performs SigComp. The role of the CSCF is to handle subscriber registration, and to support the establishment, modification and release of Instant Talk sessions. The CSCF ensures interoperability with telephone systems and network addressing mechanisms by querying domain name service (DNS) servers to map SIP uniform resource identifiers (URI) or E.164 numbers to network addresses.

In an IPMM-based service, media is directed to, replicated in, and distributed from

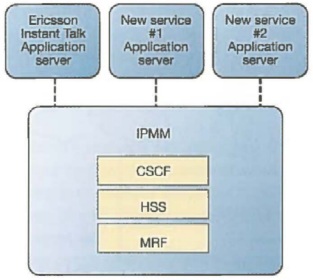

Figure 2
The IPMM system is built with service evolution in mind.

the media resource function. Because Instant Talk is a half-duplex service, the media resource function must prevent two or more users from sending media at the same time. This is called talk burst control. The MRF employs a request/response mechanism to control transmission rights. Users who want to transmit must wait until their requests have been granted. The MRF can also revoke transmission rights when a user abuses the service.

The HSS maintains the Instant Talk subscriber profile by keeping track of the core network node tasked with handling the subscriber. An evolution of the home location register (HLR) and the authentication center (AUC) used by all IMS services, the HSS also handles Instant Talk subscriber authentication and authorization functions.

Instant Talk application server

The Instant Talk application server is basically a database tool that handles subscriber data during call set-up

- to ensure that the called party is a subscriber;
- to determine who is to be included in the group during the call;
- to determine whether or not users have activated Do-not-disturb mode; and
- to check whether the user has activated manual or auto-answer mode.

The application server also stores and passes down rules and regulations to the MRF. Local policies stored in the application server typically include timer values, such as remaining talk time in a user's account.

The Instant Talk application server also supports group list management server (GLMS) functionality, which enables users with list management operations to create, modify, retrieve and delete the groups and contact lists needed for the Instant Talk service. The GMLS also provides storage space for groups and lists.

Client

Ericsson works with third parties to integrate clients into terminals from different vendors. Pre-integrated clients can be optimized for the hardware platform on which they run. For instance, to set its clients apart from downloadable clients, Ericsson can make use of the native voice codec implemented for circuit-switched calls, to increase performance and battery life.

To ensure maximum voice quality, even in environments with limited bandwidth, Ericsson employs the adaptive multirate (AMR) codec and the enhanced variable rate codec (EVRC). The AMR codec is used in EDGE, GPRS and WCDMA terminals; EVRC is used for CDMA2000 clients.

Besides SIP, Ericsson Instant Talk clients use the real-time transport protocol (RTP) to carry real-time data generated by the voice codec. Frame bundling is used to reduce the effect of relatively large headers in the IP/UDP/RTP layers. This means that several voice codec frames are sent in one RTP packet. As dictated by IETF, the frame-bundling feature is supported in the AMR and EVRC payload format. Built-in functionality in the MRF makes it possible to order clients to change the number of frames in an RTP packet to adapt to current network conditions. The MRF employs the RTP control protocol (RTCP) to monitor the network.

Standardization

The Ericsson Instant Talk solution is based on the PoC industry standard, initially developed by an industry consortium made up of Ericsson, Motorola, Nokia, and Siemens mobile, and supported by AT&T Wireless Services, Cingular, Sonim Technologies, and Sony Ericsson. It is an open, published and demonstrated interoperable multi-vendor specification. PoC Phase I includes detailed specifications that mandate the requirements and architecture of the solution. In additon to the Stage 1 and 2 specifications, the consortium also developed a complete Stage 3 suite of PoC specifications that stipulate signaling flows, user-plane flows (including talk burst control mechanisms), and group and list management methods. One of the specifications applies specifically to the radio access network, describing the recommended QoS attributes of the radio link and the operation of the voice codec. To avoid market segmentation, Ericsson has striven for an open standard that avoids lock-in and creates interoperability between operators and between terminals from different vendors.

Ericsson and the other members of the consortium have submitted the Phase 1 specification to OMA. The OMA process is moving forward, and the PoC Phase 1 specification has formed a basis for the OMA PoC standard. Further development will include new features in the PoC specifications, such as a standardized presence solution (Figure 3), an enhanced authentication method, and a network-to-network interface to enable charging between operators and to make the PoC solution compatible with additional radio access networks (WCDMA and CDMA2000). As the OMA PoC standard evolves, the Ericsson Instant talk product will be updated.

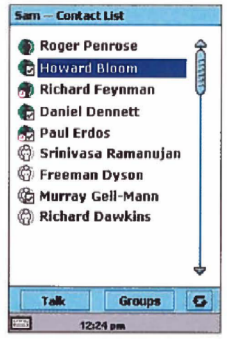

Figure 3
Mobile presence makes everyday communication easier.

Conclusion

Ericsson Instant Talk is the first of many IP-based applications that will be available over IPMM, which is based on the 3GPP IMS standard. The applications running on IPMM are controlled using SIP and SigComp (to make SIP efficient in mobile communications).

Instant Talk consists of three parts: the IPMM system, which can be reused in future applications, the Instant Talk Application Server, and the handset client. Instant Talk is fully compliant with PoC specifications, which ensures interoperability and facilitates rapid uptake of service.

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Modularity is key when designing packet backbone networks for mobile services

Araceli Calle, Alberto Fernandez Bravo, Mounir Merhi, Jens Poscher and Helena Stjerna

Ericsson has developed a verified reference network design that optimally integrates general packet radio service (GPRS) and wideband code-division multiple access (WCDMA) technology with site and backbone IP infrastructure. The solution, called Mobile Packet Backbone Network, or Mobile-PBN, unites Ericsson's core network products, and includes, among other things, optimum designs for the service network, the network management center, and network synchronization. The solution is offered as part of Ericsson's network design services.

The authors introduce the modular Mobile-PBN concept and describe some of its key modules—the multiservice backbone, circuit-switched layered architecture, and service network. They also describe the challenges associated with verifying the Mobile-PBN and how these have been solved in the context of an end-to-end network. The Mobile-PBN frequency synchronization solution has been described in a separate article.[1]

Background

The introduction of new access and core technologies as well as the convergence of packet- and circuit-switched traffic in mobile networks is a challenge for mobile operators, because they are responsible for network infrastructure and must deal with network complexity, diverging requirements and node limitations.

All too often, new nodes are introduced into operator networks using *ad hoc* network design with the aim of making the system work quickly. But the inevitable result of improper network design is an inflexible and unscalable network that cannot cope well with even minor changes. To avoid a complete redesign (which could jeopardize past investments) after the network has been taken into operation and the subscriber base is growing, operators are often forced to accept costly add-ons and workarounds.

Ericsson has collaborated with third-party networking vendors, such as Juniper Networks, Extreme Networks, NetScreen Technologies (now part of Juniper Networks), and F5 Networks, to tackle these issues and provide a strong solution—the Mobile-PBN reference design.

Operator benefits

The Mobile-PBN solution has been optimized and verified to work for networks of any size, including multi-site networks. Offered as part of Ericsson's professional network design services, the solution

- reduces costs of network design, verification and type acceptance, which translates into shorter time to revenue (Figure 2);
- reduces risks—it has been verified, is scalable, and future-proof;
- relieves operators of the cumbersome task of network design—they can rely on Ericsson's professional services staff to adapt the solution to existing networks and instead concentrate more fully on crucial revenue-generating end-user services; and
- reduces supplier relationships—Ericsson owns the overall solution and assumes responsibility for designing, migrating and supporting the entire network, and guarantees integration into Ericsson core network and GPRS and WCDMA solutions.

In addition, operators receive a verified, highly flexible, and future-proof network

BOX A, TERMS AND ABBREVIATIONS

3GPP	Third-generation Partnership Project
A2EA	AAL2 service end-point address
AAL2	ATM adaptation layer-2
AMR	Adaptive multirate
ATM	Asynchronous transfer mode
BGP	Border gateway protocol
BICC	Bearer-independent call control
CAMEL	Customized applications for mobile network-enhanced logic
CAP	CAMEL application part
CAPEX	Capital expenditure
CoS	Class of service
Diffserv	Differentiated services
DNS	Domain name server
DSCP	Diffserv code point
FRR	Fast reroute
FWLB	Firewall load balancer
GCP	Gateway control protocol
GGSN	Gateway GSN
GMSC	Gateway MSC
GPRS	General packet radio system
GSM	Global system for mobile communication
GSN	GPRS service node
IGP	Interior gateway protocol
iLB	Internal load balancer
IMS	IP multimedia subsystem
IP	Internet protocol
ISDN	Integrated services digital network
ISUP	ISDN user part
IT	Information technology
L2/L3	Layer-2/layer-3
LSP	Label-switched path
MAP	Mobile application part
MGW	Media gateway
M-MGW	Mobile MGw
MP-BGP	Multiprotocol BGP
MPLS	Multiprotocol label switching
MSC	Mobile switching center
MTP3	Message transfer protocol 3
NAT	Network address translation
NTP	Network time protocol
O&M	Operation and maintenance
OPEX	Operating expenditure
OSPF	Open shortest path first
PAT	Port address translation
PBN	Packet backbone network
PCM	Pulse-code modulation
PDB	Per-domain behavior
PDU	Protocol data units
PFE	Packet-forwarding engine
PHB	Per-hop behavior
PLMN	Public land mobile network
PoI	Points of interconnection
PoP	Point of presence
PSTN	Public switched telephone network
PVC	Permanent virtual circuit
QoS	Quality of service
RAN	Radio access network
RANAP	RAN application part
RE	Routing engine
RED	Random early discard
RNC	Radio network controller
RNS	Radio network subsystem
RNSAP	RNS application part
RSVP	Resource reservation protocol
RSVP-TE	RSVP with traffic engineering extensions
SAPI	Service access and protection infrastructure
SDH	Synchronous digital hierarchy
SGSN	Serving GSN
SGW	Signaling gateway
SIGTRAN	Signaling transport
SLB	Server load balancer
SNF	Service network framework
SN-IPI	Service network IP infrastructure
SONET	Synchronous optical network
SPF	Shortest path first
SS7	Signaling system no. 7
STM-1	Synchronous transfer mode data rate 1 (155.52 Mbps)
STP	Signal transfer point
TCP	Transmission control protocol
TDM	Time-division multiplexing
TrFO	Transcoder-free operation
TSC	Transit switching center
UMTS	Universal mobile telecommunications system
UTRAN	UMTS terrestrial radio access network
VPN	Virtual private network
WCDMA	Wideband code-division multiple access
WRED	Weighted RED
WRR	Weighted round-robin

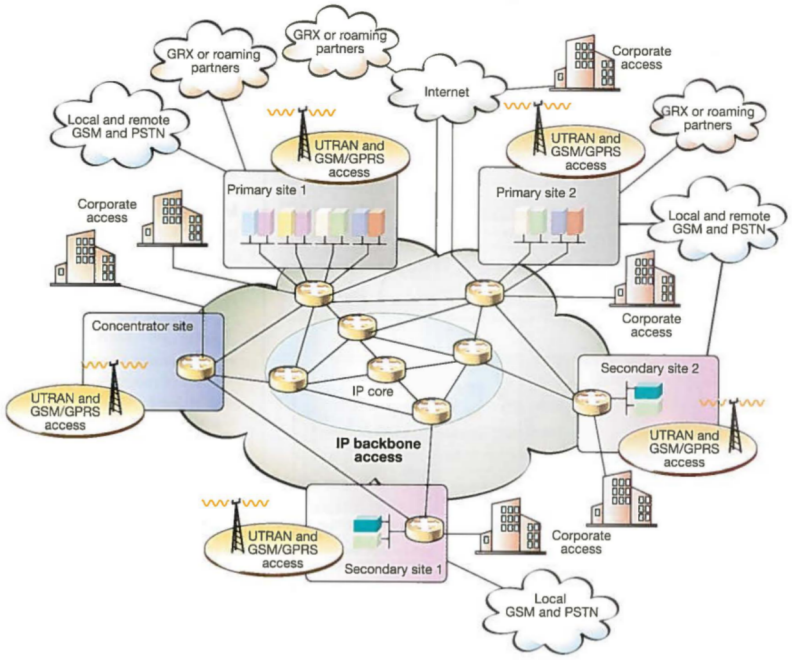
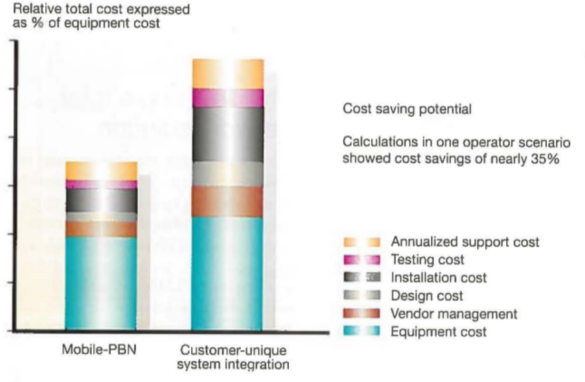


Figure 1
The Mobile-PBN reference network.

Figure 2
Benefits of Mobile-PBN: reduced time and costs of system integration.



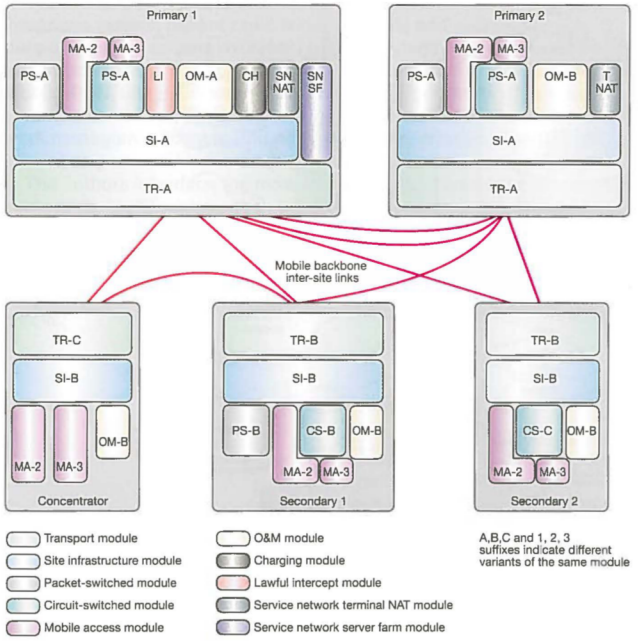


Figure 3
Mobile-PBN modules by site and function in a multi-site environment.

design to which any number of modules can be added—for example, corporate access, network management and data optimization.

Mobile-PBN, a total network solution

The Mobile-PBN solution consists of network modules that combine to provide network functions built on backbone and site infrastructure. The modules contain functionality for GPRS and WCDMA, circuit-switched voice, packet-switched data (including inter-PLMN roaming and corporate access), service network IP infrastructure (including Internet access), charging, data optimization, network management and lawful interception.

The site infrastructure provides dense Ethernet connectivity, switching functionality, frequency synchronization, network time protocol (NTP), and domain name server (DNS) services. The transport modules use IP routers or asynchronous transfer mode (ATM) switches to implement the core, distribution and access layers needed for inter-site connectivity.

Mobile-PBN reference design

The modular concept simplifies the definition of different kinds of site. The Mobile-PBN uses these definitions to design and dimension a detailed reference network for a "virtual operator" (Figure 3). The network consists of

- two Primary sites—these include the majority of modules, in particular, the operation and maintenance (O&M) module, which is needed for managing the complete network;
- two Secondary sites—these have fewer modules but maintain core network functionality; and
- a Concentrator site—this is mainly for mobile access and corporate connectivity.

The reference network is dimensioned to support a very large number of GSM and WCDMA subscribers. Besides the large reference design, the Mobile-PBN contains two very cost-effective designs for small, single-site networks. The first is a pure packet-switched solution that makes use of Ericsson's combined GPRS service node (CGSN); the second is a split serving GSN and gateway GSN (SGSN-GGSN) design with added circuit-switched functionality. Each network includes advanced security protection using firewalls and can be migrated to the multi-site Mobile-PBN design.

The reference design meets operator requirements for availability, redundancy, security and scalability. Security considerations include a policy and multi-layered security architecture that defines logical security zones and areas of physical access. Traffic is not allowed to move from one zone to another without fulfilling the conditions of pre-configured firewall policies.

Multiservice IP backbone

Most operator networks already have, or will include, geographically distributed sites connected by a transport infrastructure. Although a variety of switching equipment can be used to transport different services, there is a more profitable approach, namely common transport. Simplifying the network in this manner reduces capital expenditure (CAPEX) and eliminates the overhead of operating and maintaining multiple transport networks. It also significantly lowers operating expenditures (OPEX). The Ericsson Mobile-PBN facilitates convergence by providing backbone transport modules built around best-in-class IP routers that can support the most stringent services required by present-day and future GPRS and WCDMA networks.

Challenges of designing a packet backbone network

Interfaces

The first requirement put on a multiservice backbone is that it must be able to replace legacy network equipment. In this context, it is clear that the transport modules in the backbone must provide the same kinds of interfaces as offered by existing networks (Figure 4). The site routers of the Mobile-PBN have been selected to offer a rich variety of interfaces. They allow connections to ATM and Frame Relay and are frequently used to connect core nodes and peering networks. For Ethernet-based interfaces, the preferred means of aggregation, and of optimizing costs, is to use the Ethernet switches in the site infrastructure.

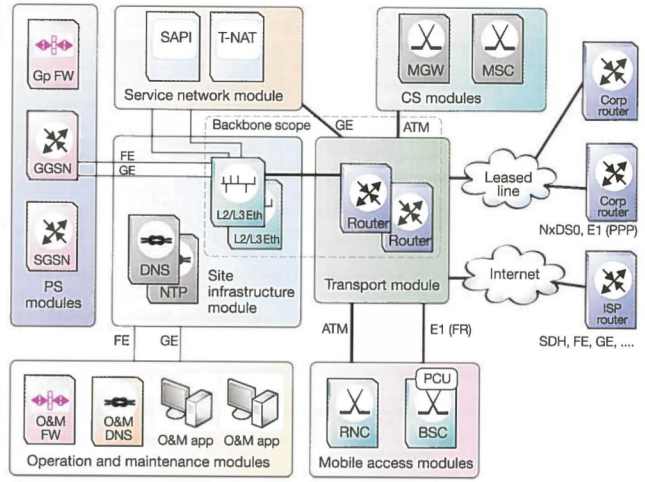


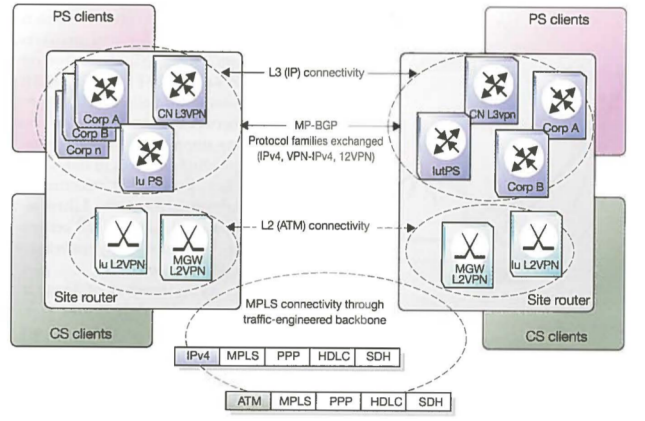
Figure 4
Mobile-PBN backbone interfaces in the Mobile-PBN.

Traffic separation in VPNs

Unfortunately, multiservice backbone integration is not as simple as "plugging" client nodes into a new box. Different client networks need distinct transport services in separate network layers (Figure 5). For instance, in the Core Network 3.0 timeframe, Ericsson's mobile media gateway (M-MGW) can deliver circuit-switched traffic in the form of IP packets (limited availability) or ATM adaptation layer-2 (AAL2) ATM cells. The latter solution requires functionality not found in ordinary IP backbones. The Mobile-PBN backbone provides this functionality using virtual private networks (VPN) based on multiprotocol label switching (MPLS).

MPLS is a key technology enabler, which in conjunction with other protocols, provides a common framework that supports Kompella layer-2 and RFC 2547bis layer-3 VPNs in an effective and scalable way. MPLS separates the control plane (which remains IP) from the forwarding plane, there-

Figure 5
Traffic separation in the backbone.



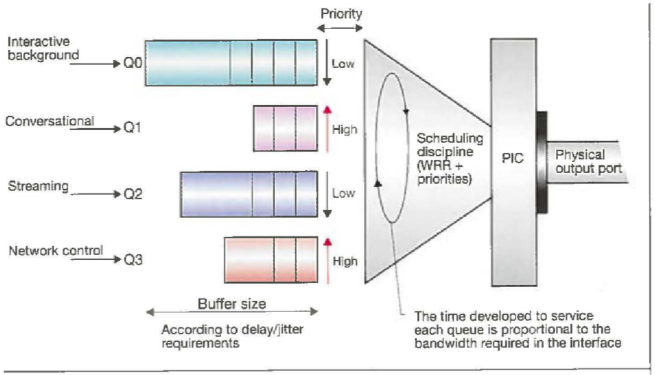


Figure 6
PHB implementation at site routers—queue, weight and priority configurations.

by solving the problem of forwarding non-IP protocol data units (PDU). Switching in the backbone is thus no longer dependent on looking up IP headers, because the forwarding of layer-2 and layer-3 (L2/L3) PDUs is based on MPLS labels, which are prepended to the PDUs when they enter the backbone. The core of the aforementioned control plane is based on the border gateway protocol (BGP) with multiprotocol extensions (MP-BGP) and traffic-engineering-enhanced link-state internal gateway protocol (IGP)—for example, open shortest path first (OSPF)—and finally, on the resource reservation protocol (RSVP).

The flexibility of a large-scale protocol like MP-BGP makes it possible to exchange VPN information (associated interfaces, encapsulation, topology, and so on) on the different VPN types. OSPF and RSVP-TE permit label-switched paths (LSP) to be implemented between network sites without the constraints imposed by shortest path first (SPF) algorithms inherent in link-state protocols. Thus, we see that transmission resources are used efficiently. Likewise, system availability is maintained because the SPF algorithms can quickly converge when the topology changes.

The ability to transport traffic on different layers is not the only benefit of VPNs. Addressing and numbering issues are also greatly simplified, because client networks perceive the backbone as if it were dedicated—a benefit that eliminates complex coordination between the client networks.

Traffic differentiation

The backbone is also greatly simplified thanks to a reduction in infrastructure and because traffic flows that were previously carried independently can now share network elements and transmission resources. If contention occurs, quality-of-service (QoS) mechanisms ensure that each type of traffic is forwarded according to its requirements.

The QoS solution for the backbone employs differentiated services (Diffserv) over MPLS. From a design point of view, the following points must be considered:

- ability of the backbone to implement forwarding treatments or per-hop behaviors (PHB) to which the traffic flows are mapped according to traffic class;
- ability of client nodes to communicate the correct QoS requirement; and
- mechanisms for dealing with local and backbone-wide congestion.

Implementing PHBs

The success of this type of solution relies on the selection of a scheduling algorithm that serves the queues used to implement the PHBs at each site router (Figure 6). The routers from Juniper Networks employ a combination of weighted round-robin (WRR) and priority disciplines, which define two priority levels. The approach upholds the strict delay and jitter requirements associated with voice traffic while giving fair treatment to lower-priority traffic classes.

Each PHB definition must also be complemented with buffer sizes that are appropriate for the delay or jitter characteristics of the traffic class to be served. In addition, for each PHB, a percentage of the available bandwidth must be allocated between each pair of sites according to relative traffic volumes. The coherent application of PHBs through the backbone routers leads to per-domain behaviors (PDB), which is to say that bearer services remain between required levels, regardless of which path is followed through the backbone.

Communicating QoS needs

Diffserv code points (DSCP) are used to map traffic flows to the appropriate PHBs. The DSCPs are inserted by the client node or can be allocated to the L2/L3 PDUs as they enter the backbone. Diffserv-capable nodes, such as GSNs, insert a DSCP that adequately reflects the PDP context. The common procedure, when the same organization owns the core and backbone networks, is to support this DSCP from an end-to-end perspective. If the IP nodes cannot handle Diffserv (for example, P2.1 RNCs), then the ingress site router inserts the DSCP based on a multi-field discriminator filter configured in the site router interface that connects to the client node.

Non-IP client nodes, such as media gateways that deliver AAL2 ATM cells, can use the site router resources by mapping the connecting interface (logical or physical) to the proper forwarding class in the ingress router. This mapping is defined when the interface is configured.

In every case, Diffserv treatment in the MPLS backbone network is encoded in the MPLS header using E-LSPs. This means that the applicable quality of service is derived from the experimental bits in the MPLS header (Figure 7).

Dealing with congestion

To work effectively, the QoS approach requires mechanisms for dealing with local and backbone-wide congestion. The mechanism for managing local congestion, called weighted random early discard (WRED), enables different drop profiles to be assigned to different kinds of traffic. A less aggressive random early discard (RED) drop profile is assigned to critical packets; a more aggressive profile is assigned to other packet types.

With the exception of transmission control protocol (TCP) traffic, this mechanism by itself is not sufficient to avoid long-term congestion. A backbone-wide solution which is based on traffic conditioning at the edges of the backbone and which is valid for all kinds of traffic must be employed to keep traffic injected by different sources within acceptable limits. Ericsson recommends that policers should be employed in the site router interfaces connected to client nodes. The policing mechanism in routers from Juniper Networks employs the token bucket algorithm, which enforces a limit on average bandwidth while allowing bursts of up to a specified maximum value.

Availability

The infrastructure must also offer the same level of availability found in existing public telecommunications networks. The Mobile-PBN view is that reliable services are built on top of reliable networks, which in turn, are based on reliable platforms.

The Mobile-PBN recommends the usage of IP routing devices with separate routing and forwarding planes. This gives efficient deployment of graceful restart implementations of the protocols used in the control plane. Separation guarantees the performance of the packet-forwarding engine (PFE) even with high levels of route instability. Moreover, even extremely large volumes of traffic cannot limit the ability of the routing engine (RE) to maintain peer relationships and calculate routing tables. In short, a clean separation of these two functions yields superior forwarding performance and a highly reliable system.

Equipping the routers with redundant routing engines and packet-forwarding engines further increases availability. The routing engines support hitless failover, which means that in the event of failure or planned downtime (for software upgrades) the packet-forwarding engine can maintain forwarding while the redundant routing engine takes over (for a period of, say, 2-3 minutes).

The introduction of robust routers does not, in itself, guarantee the required levels of reliability—the backbone must still be protected against link failures and the risk of node failures. Because the Mobile-PBN is a converged MPLS infrastructure, MPLS traffic protection mechanisms are also necessary (Figure 8). To meet the stringent requirements imposed by voice traffic, it is

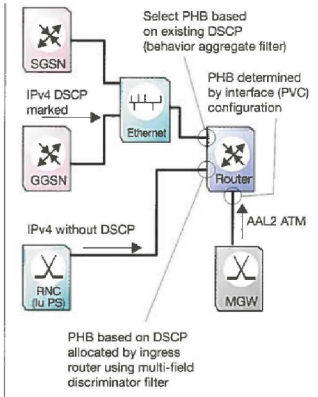
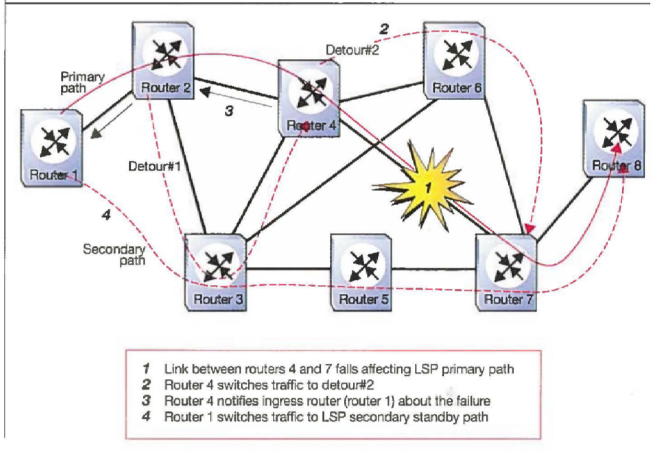


Figure 7
Determining QoS for different types of client nodes.

Figure 8
MPLS traffic-protection mechanisms applied to the backbone.



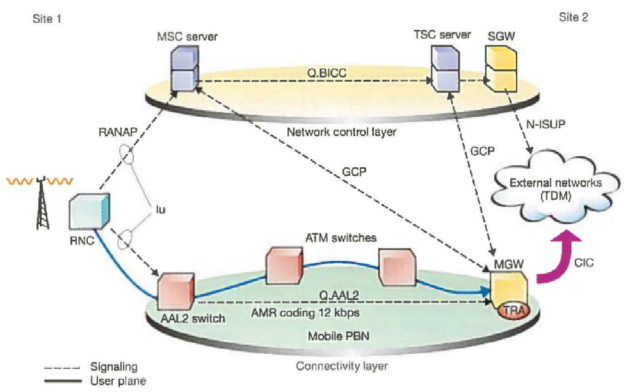


Figure 9
Schematic view of the layered architecture.

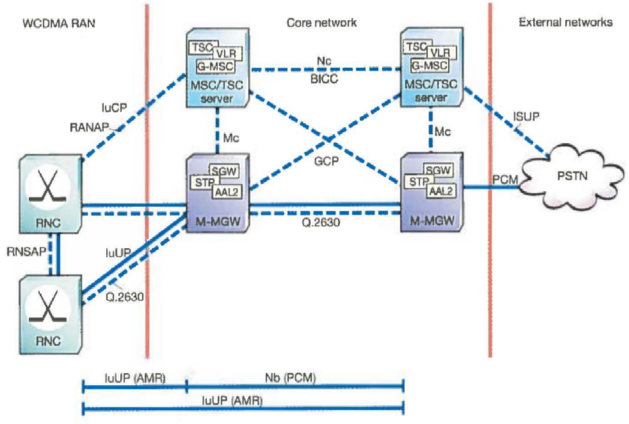
recommended that two levels of pre-computed label-switched paths be used. At local levels, the fast reroute (FRR) mechanism is used. At backbone-wide levels, secondary standby paths are recommended.

The fast reroute mechanism provides alternative paths that the router upstream of an outage can use to quickly reroute traffic around a failed link or node. The same router notifies the ingress router about the failure, causing it to switch traffic to the secondary path. The use of pre-computed alternate paths significantly reduces recovery times. Indeed, it puts them on a par with SDH/SONET protection mechanisms. To be effective, the secondary paths and other alternative paths must not share fate with the primary label-switched path.

In large networks, the combination of these two mechanisms (FFR and secondary standby paths) provides optimum traffic protection. In networks with simpler topology, such as the Mobile-PBN reference network, secondary standby paths suffice.

To obtain the best results when applying these mechanisms, Ericsson recommends compliance, at physical and logical levels, with a set of connectivity guidelines for the backbone and different client networks.

Figure 10
Interfaces used in the layered architecture.



Circuit-switched layered architecture

The Third-generation Partnership Project (3GPP Release 4) has standardized the circuit-switched layered architecture in response to operator requirements

- to cut costs in the transmission network;
- to aggregate O&M-intensive nodes in central sites; and
- to spread the public switched telephone network (PSTN) points of interconnection (PoI) close to the destination, to obtain local switching.

Ericsson's solution to the circuit-switched layered architecture, which is based on mobile switching center (MSC) servers and mobile MGWs, enables operators to introduce the new technology using ATM in the transport network (for the user-plane) and signaling system no. 7 (SS7) signaling. A step-by-step evolution simplifies migration of the core network to IP. The first step entails the introduction of SS7 over IP signaling transport (SIGTRAN) for control signaling. Later, the user-plane in the core network will also be based on IP transport.

Core network architecture

The control and connectivity layers in the circuit-switched layered architecture are logically separated. However, the servers (MSC, GMSC, TSC and SGW) retain the signaling protocols used in the non-layered architecture. Two additional protocols—the bearer-independent call control (BICC) and gateway control protocol (GCP)—are also implemented (Figure 9). BICC introduces control of ATM and IP bearers in the connectivity layer. GCP enables the servers to control and manipulate the resources of a media gateway. Legacy narrowband protocols might also need a signaling gateway (SGW) to convert signaling bearers.

Benefits

The new architecture helps reduce the costs of operating the network. In traditional networks, the MSC and transit switching center (TSC) nodes are not centralized. Consequently, daily maintenance and hardware and software upgrades require O&M personnel to work from several locations.

Leased lines in the TDM-based core network are dimensioned for 64 kbps voice channels. Existing voice compression systems are not end-to-end solutions. However, setting up a network in the layered architecture to place the voice transcoders at the edge of the network permits true end-to-end transmission of coded voice to save bandwidth in the backbone. In addition, voice quality enhancements, such as transcoder-free operation (TrFO), which was standardized in 3GPP Release 4, will soon become available.

Another benefit of the new architecture is the decentralization of media gateways, which allows the opening of multiple PSTN points of interconnection and enables operators to carry calls as far as possible in their own networks.

Technology

The initial solution for the layered core network is based on an ATM network with AAL2 switching. The functionality and benefits of AAL2 switching with statistical multiplexing in the UMTS terrestrial radio access network (UTRAN) have been discussed previously.[2] Figure 10 shows all relevant payload and signaling interfaces.

The Ericsson mobile media gateway combines all transcoder, echo canceller, and multi-part device functionality. A signaling gateway is added on top of the mobile media gateway to convert the SS7 signaling bearer from ATM to TDM and vice versa. The M-MGW serves as a cross-connect for ATM permanent virtual circuits (PVC) and as an AAL2 switch. AAL2 switch functionality is especially important for the codec-at-the-edge feature, and for redundancy at higher layers.

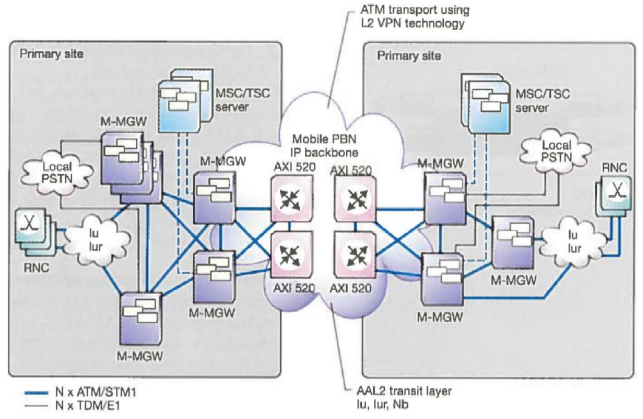


Figure 11
Mobile-PBN circuit-switched reference design.

Thanks to AAL2 switching and dedicated bearer control protocols (Q2630 or Q.AAL2) in the transport layer, the *Iu* interface can be extended through the core network domain to serve the nearest M-MGW of the region to which a call is to be delivered. The radio network controller (RNC) sets up the AAL2 connection hop-by-hop to the final M-MGW. It uses the AAL2 service end-point address (A2EA) to address the destination node. Only one media gateway is needed to transcode AMR-coded voice over *Iu* from the RNC to pulse code modulated (PCM) voice. Operators thus save bandwidth in the backbone—PCM requires the equivalent of 84.8 kbps in bandwidth, whereas AMR-coded voice over *Iu* requires only 12.2 kbps end-to-end. The same AAL2 network also facilitates *Iur* connections between RNCs. The next step is to build a core network that is as resilient and delivers the same perceived quality of service as TDM-based networks.

Mobile-PBN circuit-switched design

The Primary sites aggregate the MSC and TSC servers as control layer nodes. The MSC servers control the RNCs. For optimal call routing, the MSC servers also control every M-MGW in the network. The Secondary sites only contain M-MGWs. The MSC

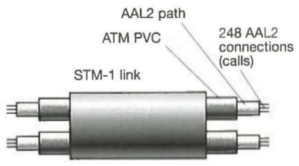


Figure 12
AAL2 connections.

servers in the Primary sites control the RNCs and MGWs in the Secondary sites via GCP. The Concentrator sites solely contain the WCDMA access module.

The sites are interconnected by the multiservice backbone. The different sites tunnel ATM traffic through using layer-2 VPNs. This modular approach enables Mobile-PBN networks to scale from one-site solutions to very large WCDMA networks.

Connectivity

Ericsson's layered architecture solution calls for static ATM PVCs between each node in the AAL2 network. Each ATM PVC carries one AAL2 path, which in turn, can carry 248 AAL2 connections or calls (Figure 12).

Obviously, given the growing number of M-MGWs, a full mesh of physical links would be uneconomical and difficult to manage. An alternative approach is to connect the M-MGWs by means of cross-connected ATM PVCs, but this is also quite complex. Therefore, to achieve full connectivity of M-MGWs and the required redundancy on the AAL2 switching layer, Ericsson has introduced access layer and transit layer hierarchy.

The concept is similar to legacy TDM or IP networks. Two M-MGWs at each site belong to the AAL2 transit layer. Every AAL2 transit M-MGW is fully meshed over the backbone using label-switched paths. Therefore, should the AAL2 path or node fail, the destination site can still be reached. The backbone is responsible for internal AAL2 path redundancy (Figure 8).

The remaining M-MGWs at the site connect on the AAL2 layer to the two transit M-MGWs. From the viewpoint of the AAL2 layer, the RNC must adhere to this same structure—that is, each RNC must connect to two different M-MGWs over redundant links. Thanks to this modular architecture, every AAL2-based interface (*Nb*, *Iu*, *Iur*) can use this transport layer. If a link, board or the next AAL2 switch fails, an alternate route is always available.

This strictly hierarchical network also allows certain nodes to be grouped in A2EA addressing—for example, the nodes at a site. This, in turn, makes it possible to use single routing entries for sites, because the transit AAL2 switches must only analyze the longest prefix in the address field. What is more, the addition of nodes only requires changes in a few routing tables.

To guarantee redundancy, the MSC and TSC servers must connect to two M-MGWs, which also serve as signal transfer points (STP). The internal STP functionality of the M-MGW forms the new broadband SS7 network. The broadband SS7 layer mirrors the hierarchical structure of the AAL2 layer. The transit M-MGWs, which make up the transit SS7 STP network, route all inter-site signaling (RANAP, RNSAP, GCP, MAP, CAP, BICC and ISUP) on the message transfer protocol 3 (MTP3) level.

IP infrastructure of the service network

The service network framework (SNF) is an architectural framework that consists of reusable designs for products and solutions in the service layer.[3] This includes the IP network used for deploying the service network.

The SNF deployment view provides guidelines for ensuring that the IP network contains a set of common services and qualities on which every deployed system can rely. Examples of common services include naming, addressing, routing, load-balancing, firewall, and security gateway services. Common qualities include performance, scalability, flexibility, security and high availability. The Mobile-PBN thus employs a service network IP infrastructure (SN-IPI) that gives users of the Mobile Internet access to services hosted at the server farm, and mobile users access to the Internet.

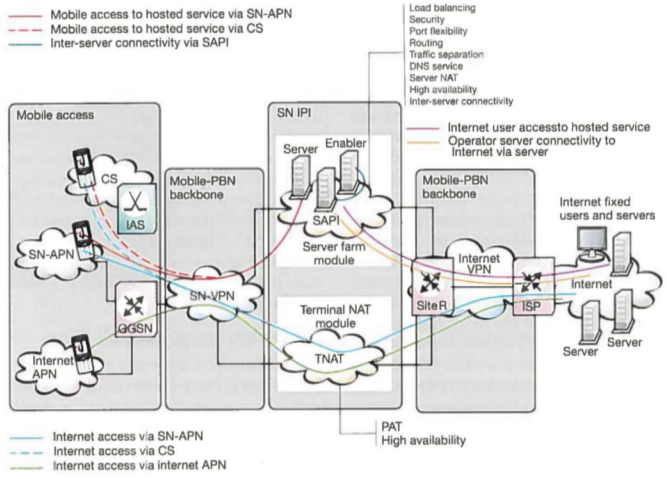
The SN-IPI introduces two functional modules: the server farm module and the terminal NAT module. The server farm module provides services to mobile and Internet users. It contains the service access and protection infrastructure (SAPI), service enablers, and application servers located in the mobile operator's service network. The terminal NAT modules provide the network address translation (NAT) functionality needed to map a private address to a public IP address when mobile subscribers want to access the Internet. As seen in Figure 13, the Mobile-PBN backbone makes use of SN-IPI modules and IP transport services to accommodate several traffic flows.

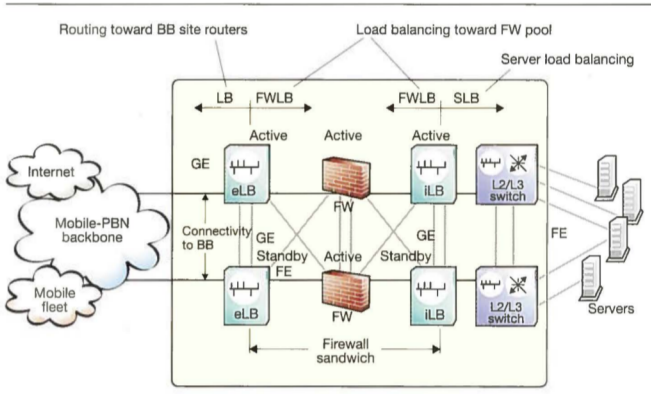
Server farm modules

In the context of the SN-IPI, the main system in a server farm module is the SAPI (Figure 14). The other systems of the server farm (enablers, application and content servers) are integrated into the SAPI, which consists of a set of firewalls placed between two pairs of load balancers—in this case, firewall load balancers (FWLB). This setup ensures incremental scalability. In other words, operators can add more firewall protection as capacity increases. The internal load balancers (iLB) also serve as load balancers for servers that scale horizontally. L2/L3 switches are used to provide flexible, high-port density to connect all enablers and services. Figure 14 shows how these components are interconnected.

Apart from providing physical connectivity and protecting servers, the SAPI also

Figure 13
Role of SN-IP infrastructure in mobile networks.





SAPI (Service access and protection infrastructure)

Figure 14
Service access and protection infrastructure.

provides address translation—it supports one-to-one and many-to-one address translation.

A small package solution is offered for smaller deployments of server farm modules. The module replaces external load balancers with standard L2/L3 switches. There are two variants for the internal server side. The first includes internal load-balancer units, used only as server load balancers and not as firewall load balancers. If necessary, standard L2/L3 switches can also be used to increase the number of ports or to connect to certain nodes, such as those that are based on TSP. The second variant includes internal load balancers. This solution is provided for operators who do not need load-balancing functionality.

The Mobile-PBN also provides support for integrating the following enablers and application servers into SAPI: USIS 1.0, DNS IPWorks 4.1, HTTP/FTP proxy (proxy + SSL), EMA 3.2, SNOS 1.0, MIEP 2.0 and MMS 3.0.

Terminal NAT module

The terminal NAT module consists of two switches that serve as NAT devices in an active-standby mode—if one of them fails, the other automatically takes over. In terms of deployment, the terminal NAT functionality is distributed in the same way as Internet point of presence (PoP). Ideally, a NAT module should be deployed near the point of presence (PoP). This reduces the mobile operator's transmission costs by delivering traffic to the Internet as soon as possible.

Verification of the Mobile-PBN solution

Although the integration of new equipment and features is a critical issue in modern telecommunications networks, all planned and unplanned downtime disturbs active traffic and decreases revenue. To shorten integration times, the Mobile-PBN verifies the basic and new aspects of each design module before the design can be released.

The Mobile-PBN solution is set up and tested inside an end-to-end environment. The Ericsson Eurolab Deutschland GmbH verification center and the Ericsson AB HotLab have several interconnected labs that provide the basic infrastructure for integrating every piece of equipment—site routers, switches, firewalls, and load balancers—with core network nodes (SGSN, GGSN, MSC, and M-MGW).

The modularity, flexibility and scalability of the Mobile-PBN are vital features for verification in the end-to-end test networks. These network characteristics ease the integration of a customized solution into an existing customer network.

TABLE 1, VERIFICATION ACTIVITIES COVERED BY THE MOBILE-PBN SOLUTION

- Connectivity and integration
- Security
- Resilience/redundancy
- Quality of service traffic management
- Operation and maintenance
- Load and characteristics
- Service network integration and the service network IP infrastructure with server farm and terminal NAT
- Data optimization
- Flexible bearer charging
- Small network (single-site solution)
- Network synchronization

Test cases are defined to expose potential problems and to verify design concepts before they reach the field. Verification reveals different kinds of faults or unexpected behavior in the equipment and network configuration. Because the network is operational, the test cases also show how it can be tuned for optimum performance. Traffic simulators and automated test patterns are used to simulate real radio network loading based on Ericsson's experience. These are used to stress the network to ensure correct behavior under load, which is essential for verifying operation of QoS delivery. Trouble Reports are written on all Ericsson and partner products. All problems and solutions are documented in test reports.

By discovering and resolving faults and unexpected effects, Ericsson makes the Mobile-PBN a more reliable network solution for the end-customer. Table 1 lists the test areas and extent of the Mobile-PBN verification activities.

Conclusion

This article demonstrates the strength of Ericsson's Mobile-PBN modular design concept:

- functional modules such as the circuit-switched (layered architecture) and service-network modules, can easily be plugged into the transport modules (multiservice backbone and site infrastructure);
- other modules can be added easily when needed;
- the evolution of the backbone and site infrastructure is optimally aligned with the transport needs of the core network nodes (circuit- and packet-switched) and new packet-based services; and
- the network can readily be expanded using larger modules or adding new ones.

The design uses methods that cover a wide range of interconnected network areas and provide the following network-wide attributes:

- strong security at every level;
- class-of-service (CoS) differentiation;
- high availability (through physical and logical redundancy mechanisms);
- traffic separation (allowing overlapping IP address ranges for connected corporations); and
- intra- and inter-site connectivity.

A backbone and site infrastructure network design based on Ericsson's verified Mobile-PBN solution provides operators with many advantages—not only in terms of reduced costs and minimized risks, but also in terms of network interoperability, scalability and migration. With this solid foundation, operators can concentrate on providing attractive and cost-effective end-user services.

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Network synchronization—Stand-alone products that support the design of synchronization networks

Stefano Ruffini

The telecommunications industry acknowledges the importance of good network synchronization, in particular, following the introduction of digital techniques and telecommunications technologies such as WCDMA. What is more, the introduction of Ethernet networks, and the growing number of hybrid (packet- and circuit-switched) network architectures makes clear the requirement to maintain synchronization quality as a means of guaranteeing quality of service (QoS).

To support evolving telecommunications networks, Ericsson provides effective site and network solutions—for example, the Mobile Packet Backbone Network (Mobile-PBN)—as well as specific synchronization solutions. The solutions employ products that are suitable for implementing a reliable, cost-effective and easy-to-operate, dedicated synchronization network. These products—the central building clock (CBC) and GPS system clock (GSC)—are currently available in the common site product portfolio for the core network.

The CBC is fully redundant, stand-alone synchronization equipment (SASE). The GSC is a cost-effective, stand-alone clock controlled by GPS. Each of these products is employed to provide telecommunications equipment with network frequency and time synchronization functions and has been optimized for, but is not limited to, use with Ericsson's main platforms such as AXE and CPP.

The main benefits of synchronization networks based on these products are a flatter synchronization-distribution hierarchy, improved reliability, and greatly reduced overall costs of operation and maintenance (O&M), administration, and provisioning.

The author explains why network synchronization is necessary and what can happen if it is not planned properly. He also introduces the CBC and GSC and describes how Ericsson's solutions meet the requirements of a synchronization network. Although the main focus of this article is on frequency synchronization, Ericsson's solutions also provide an accurate time synchronization reference.

Introduction

Network synchronization is a generic concept that depicts a way of distributing common time and frequency references to all the nodes of a network, to align their respective time and frequency scales (Box B). The role of network synchronization, especially in the context of frequency accuracy, has grown in importance since the late 1970s, when digital transmission and switching were introduced. Today it strongly influences the quality of most operator services.

The effect of poor synchronization in a telecommunications network is strictly related to the services carried. Digital switching equipment, for example, must be synchronized to avoid slips (Figure 1)—although slips have little effect on plain voice service, they have major impact on circuit-data services (Box C).

The deployment of synchronous optical network (SONET) and synchronous digital hierarchy (SDH) technologies in the 1990s put new and more stringent requirements on the stability of synchronization systems. This led to a large standardization effort, resulting in several new or updated recommendations.

Network synchronization plays a particularly important role in GSM and WCDMA. Looking ahead, it is also plain to see that it will have a major role in packet-switching environments. Packet switching was originally introduced to handle typically asynchronous data, but the ongoing evolution of packet networks will call for new and stricter synchronization requirements, including distributing synchronization over asynchronous media, such as Ethernet networks (Figure 2). Extensive work is already underway within relevant standardization bodies to specify requirements and solutions for the correct operation of time-division multiplexing (TDM) transport over packet networks.

BOX A, TERMS AND ABBREVIATIONS

ANSI	American National Standards Institute	IWF	Interworking function	SND	Synchronization network design
BITS	Building integrated timing supply	MGW	Media gateway	SNMP	Simple network management protocol
BSC	Base station controller	M-MGW	Mobile MGW	SNTP	Simple NTP
BTS	Base transceiver station	Mobile-PBN	Mobile Packet Backbone Network	SONET	Synchronous optical network
CBC	Central building clock	MPU	Microprocessor unit	SSM	Synchronization status message
CPP	Connectivity packet platform	MSC	Mobile switching center	SSU	Synchronization supply unit
CPU	Central processing unit	NSR	Network synchronization review	TDEV	Time deviation
DS1	Digital signal, level 1 (1544 kbps framed signal)	MTIE	Maximum TIE	TDM	Time-division multiplexing
		NTP	Network time protocol	TIE	Time interval error
E1	2048 kbps framed signal	O&M	Operation and maintenance	TL1	Transaction language no. 1
EMS	Element manager system	PDH	Plesiochronous digital hierarchy	ToD	Time of day
ETSI	European Telecommunications Standards Institute	PLMN	Public land mobile network	TSC	Transit switching center
		POTS	Plain old telephone service	UI	Unit interval
GGSN	Gateway GSN	PRC	Primary reference clock	UMTS	Universal mobile telecommunications system
GPRS	General packet radio service	PRS	Primary reference source		
GPS	Global positioning system	PSTN	Public switched telephone network	UTC	Coordinated universal time
GSC	GPS system clock			UTRAN	UMTS terrestrial radio access network
GSM	Global system for mobile communications	QoS	Quality of service	WCDMA	Wideband code-division multiple access
		SASE	Stand-alone synchronization equipment		
GSN	GPRS support node				
IP	Internet protocol	SDH	Synchronous digital hierarchy		
ITU-T	International Telecommunication Union – Telecommunications Standardization Sector	SGSN	Serving GSN		
		SGSN-G	SGSN for GSM		
		SGSN-W	SGSN for WCDMA		

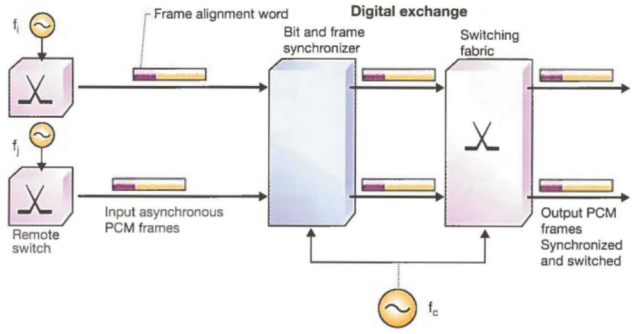


Figure 1
Slips and synchronization requirem ents of a digital exchange.

Slips are a repetition or deletion of a block of bits in a synchronous or plesiochronous bit stream due to a discrepancy in the read and write rates at a buffer.

Network synchronization strategies and best practices

Network synchronization is achieved by means of a synchronization network that distributes an accurate and reliable reference timing signal to network nodes. At present, two main technologies are used to obtain an accurate reference timing signal: Cesium clocks and clocks based on GPS. Each of these technologies provides an accurate reference timing signal that complies with the basic requirements outlined in ITU-T G.811 and ANSI T1.101.[1-2] Ordinarily, clocks of this kind are referred to as a primary reference clock (PRC) or primary reference source (PRS).

Different approaches can be used to design a synchronization network. The two most prominent (Figure 3) are

- distributed PRC—a PRC is deployed at every site that needs an accurate synchronization reference; and

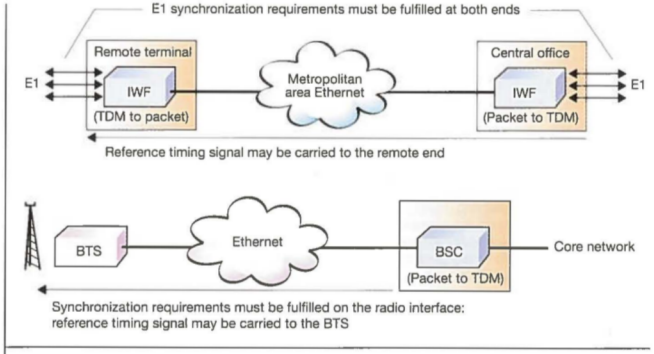


Figure 2
Examples of synchronization aspects in Ethernet networks: circuit emulation services and wireless access networks.

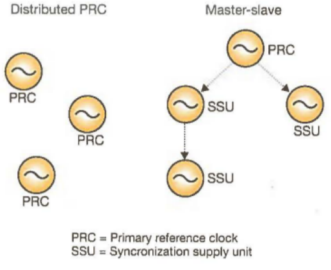


Figure 3
Distributed PRC and master-slave synchronization network.

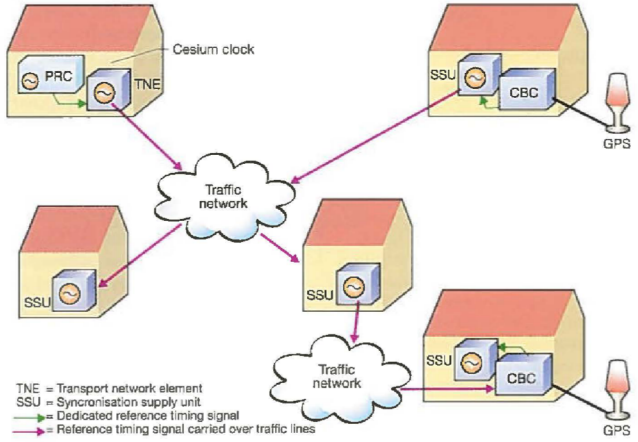


Figure 4
Example of a synchronization network.

BOX B, NETWORK SYNCHRONIZATION: FREQUENCY VS. TIME SYNCHRONIZATION

The term synchronization can mean different things depending on context and who you are talking to. Generally speaking, synchronization is the act of synchronizing the operation of different devices or processes by aligning time scales. The term is also widely used to indicate a common frequency; the more appropriate term, however, is syntonization.

Frequencies can be distributed via dedicated analog signals (typically 2048 KHz) or via digital signals that carry traffic. In the latter case, a typical application is to distribute synchronization via the traffic itself, for instance, on PDH 2048 kbps or 1544 kbps signals. The frequency reference is normally transferred from a stable and accurate clock to a clock of lesser quality via a master-slave scheme (Figure 5).

Time synchronization is the distribution of a reference absolute time, such as the national standard time, to the real-time clocks of a telecommunications network (synchronization of real-time clocks). Time synchronization is requested whenever network elements need to share a common timescale. Time synchronization has many applications in telecommunications, data communications and power utility networks—for example, precise time stamping for billing, fault isolation, security assurance and transaction processing, and for supporting quality of service (QoS).

The standard timescale of the International Telecommunication Union (ITU) is coordinated universal time (UTC), which is based on the Earth's rotation around the sun and around its axis. UTC is disciplined with respect to international atomic time (TAI) by inserting leap seconds at intervals of about 18 months. UTC can be distributed using time-of-day (ToD) information through radio and satellite navigation systems (GPS), telephone modems and portable clocks.

An effective and convenient distribution of ToD calls for a hierarchical time synchronization network and a protocol that can read a server clock, transmit the data to one or more clients, and adjust each client clock. In TCP/IP networks, the protocol of choice is the network time protocol (NTP). Developed by David Mills at the University of Delaware, NTP has become an industry standard for synchronizing time in computers and network equipment.[4] The protocol is based on messages transported over Internet protocol (IP) and user datagram protocol (UDP) packets.

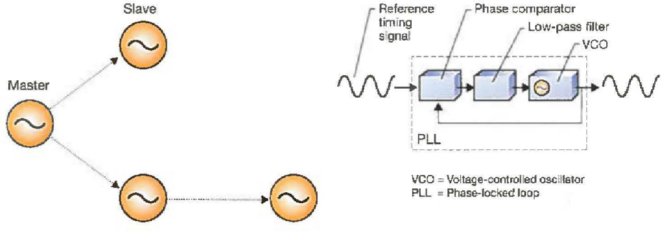


Figure 5
Master-slave method and PLL.

- master-slave—a centrally located PRC distributes the frequency reference via the traffic network or a dedicated network to remote clocks of lesser quality, for instance, synchronization supply units (SSU).

In practice, most telecommunications operators implement a mixed solution; that is, they deploy PRCs at main sites and distribute reference timing signals to remote sites via the traffic network (Figure 4).

The main cause of problems in a synchronization network is usually related to the distribution of reference timing signals via traffic networks. For example, designers need be careful to avoid timing loops in the synchronization network. Timing loops occur when a clock derives the controlling reference timing signal from itself (Figure 6). In this case all associated clocks have a large frequency offset compared to the nominal frequency and are likely to be isolated from the rest of the synchronization network. In other instances, synchronization references are sometimes distributed by leased lines that lack reliable, quality distribution of the reference. Likewise, pointer adjustments in SDH network elements can cause problems in synchronization networks.

Proceeding from analyses of current networks, work on future networks, and relevant guidelines from international standardization bodies (for example, EG 201 793, Ref 3), Ericsson has defined best practices for network synchronization. The main recommendation is to follow a distributed PRC strategy. This approach yields the most reliable and cost-effective solution and is valid in any network scenario. GPS technology facilitates cost-effective deployment of PRCs. Cesium clocks can be considered where it is not feasible to implement a solution based on GPS technology (for instance, for political reasons). Because Cesium clocks are considerably more expensive to use than GPS clocks, they are only deployed at a few main sites or sites where it is not feasible to use GPS primary reference sources. Remote sites, such as base station sites connected via reliable transmission systems, can derive synchronization references from the sites with PRCs.

The recommended site solution (intra-site synchronization) is to implement a stand-alone clock (referred to as SASE or building-integrated timing supply BITS). Ericsson calls these central building clocks (CBC) and has adopted this name for a fam-

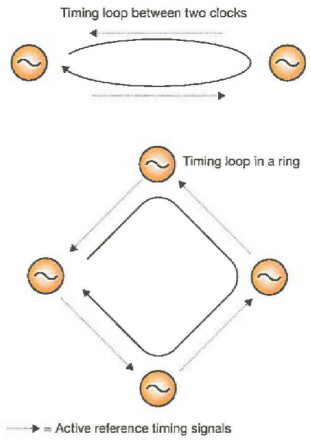


Figure 6
Timing loop.

BOX C, THE EFFECTS OF POOR SYNCHRONIZATION

To prevent loss of information when digital signals are being transported over a link, the receiving end must either operate at the same average frequency as the transmitting end (digital exchanges) or with spare bandwidth capacity (transport network equipment). This applies to every network node involved in transport between the transmitter and receiver.

The task of keeping entities operating at the same average frequency (and within proper quality boundaries) is referred to as network synchronization. If synchronization is poor—that is, if the network nodes do not operate at the same average frequency—impairments, such as slips and bit errors, will occur.

The impact of slips and bit errors in a digital network varies depending on the application and type of service. The impact is greater on services using data with low redundancy, such as narrowband video, than it is on services using data with high redundancy, such as POTS (Table 1).

A common example of impairments in GSM networks is the disconnection of calls during handover. In addition to impairments affecting transmission, consequential errors (such as blocked links) might affect the operation of single-network nodes or even network segments that cause services to be shut off completely. Ultimately, poor synchronization affects quality of service, resulting in a negative effect on operator business.

TABLE 1, POTENTIAL IMPACT OF SLIPS ON SERVICES

Service	Potential impact
Encrypted text	Encryption key must be retransmitted.
Video	Freeze frame for several seconds. Noise burst ("pop") on audio.
Digital data	Deletion or repetition of data. Possible missframe. Reduction of throughput.
Facsimile	Connection establishment might not succeed. Deletion of 4-8 scan lines or loss of throughput depending on facsimile system.
Voice band data	Transmission errors for 0.01 to 2s. Dropped call (for some modems).
Voice	Possible "click".

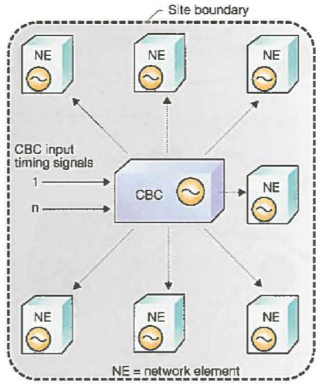


Figure 7
Central building clock (CBC) concept.

ily of equipment. CBC equipment is responsible for distributing reference timing signals to each of the network elements at a site. It monitors and supervises incoming synchronization references and, if the external references are lost, provides a high-quality holdover frequency via an internal oscillator (Figure 7). The CBC concept makes the synchronization network more visible and concentrates synchronization resources into a single device per building.

Figure 8
Photograph of a central building clock (CBC).

Ericsson network solutions

Ericsson currently offers optimized network solutions that fulfill operator requirements for appropriate network synchronization design (frequency and time synchronization). The Mobile-PBN, for example, simplifies the introduction and deployment of packet backbone networks for use in mobile networks. In particular, Mobile-PBN release 3.0 gives operators an optimized and verified solution (including a network synchronization solution) for complete network design. It is part of Ericsson Core Network release 3, which gives efficient rollout of all core network-related services. The Mobile-PBN solution is based on a multiservice backbone for cost-effective interconnection of operator sites, and makes optimized use of backbone bandwidth for voice and data. It includes a complete network-synchronization solution that complies with the recommendations issued by international standardization bodies.

Regardless of network type and technology, however, Ericsson can provide strategic consultation in the area of network synchronization, helping operators to identify and map their needs at every stage of managing the network life-cycle—from designing the synchronization network when planning a new network, to network synchronization audits in order to evaluate the quality and reliability of current network synchronization solutions.

Synchronization products

The CBC and the GSC can each provide stable timing references that are suitable for frequency and time synchronization. They have been customized for optimum integration into Ericsson site solutions—for instance, Mobile-PBN sites. The CBC and GSC are also included in the Core Network Common Site Product portfolio.

Central building clock

The CBC is a fully redundant SASE that provides the network frequency and time synchronization function to any telecommunications equipment (Figure 8). It has been optimized for, but is not limited to, use with Ericsson's main technology platforms—AXE and CPP. The main functions of the CBC are

- to receive, terminate and supervise external network synchronization reference signals;

BOX D, QUALITY PARAMETERS AND CHARACTERIZATION OF TIMING SIGNALS

Several parameters have been defined to specify and measure the quality of the synchronization network and of reference timing signals. The most commonly used parameters are

- frequency accuracy;
- jitter and wander; and
- time error—time interval error (TIE), maximum time interval error (MTIE), and time deviation (TDEV).

Frequency accuracy is defined as the maximum magnitude of the fractional frequency deviation for a specified time period (Figure 9). The fractional frequency deviation $y(t)$ is the difference between the frequency of a signal, $\upsilon(t)$, and a specified nominal frequency, υ_{nom}, divided by the nominal frequency:

$$y(t) = (\upsilon(t) - \upsilon_{nom})/\upsilon_{nom}$$

Ordinarily, frequency accuracy is measured in parts per million (PPM). The measure of frequency accuracy is strongly dependent on several external conditions that should always be specified together with the accuracy value. The most vital condition is the time period being considered. Without the time period, the stated accuracy value would have little or no significance. Environmental conditions, such as operating temperature, allowed rate of temperature change, or power supply instabilities, also influence accuracy and should be specified. The frequency accuracy of a system is given by the accuracy of its main clock oscillator.

Jitter is defined as the short-term variation of the significant instants of a digital signal from its ideal position in time (Figure 10). A common limit for defining the short-term variations is 10 Hz.

Wander is the long-term variation of the significant instants of a digital signal from its ideal position in time (where long-term implies that the variation in frequency is less than 10 Hz). The definition of wander does not usually include long-term variations caused by frequency offset and drift.

Jitter and wander are expressed in units of time, often in terms of unit intervals (UI) or nanoseconds.

Despite the similarity in definitions, jitter and wander often have different sources. One source of wander is a synchronized clock that uses a control mechanism of some kind to maintain a lock on its reference. It is this control mechanism that gives rise to wander, sometimes referred to as clock breathing. Wander can also be caused by environmental factors, such as temperature changes of transmission media. In SDH and SONET transport networks, a major contributor to wander is the pointer adjustment mechanism.

The main sources of jitter are bit-stuffing mechanisms in multiplexers and oscillator-introduced phase noise.

There are several parameters in use for specifying wander in standard specifications, in particular, the two timing parameters—MTIE and TDEV—selected to characterize transients and low frequency noise on a synchronization interface. These parameters are calculated using measured time error.

The time error of a clock, with respect to a frequency standard, is the difference between the time of the clock and the time of the frequency standard (Figure 11).

Mathematically, the time error function, $x(t)$, between a clock with time $T(t)$ and a reference clock with time $T_{ref}(t)$ is defined as

$$x(t) = T(t) - T_{ref}(t)$$

The MTIE (τ) is the maximum peak-to-peak time error of a given timing signal, with respect to an ideal timing signal, within an observation interval (τ), for all observation times with said length within a specified measurement period.

TDEV is a measure of the expected time error of a signal as a function of integration time. It can also provide information on the spectral content of the phase (or time) noise of a signal.

MTIE is useful for capturing the phase transients in a timing signal, because it describes the maximum phase variation of a timing signal over a period of time. However, because of its sensitivity to phase transients, MTIE does not adequately show the underlying noise on the timing signal.

Random noise is better characterized by TDEV, which is a root-mean-square (RMS) power estimator rather than a peak estimator. TDEV tends to remove transients in a timing signal, and is therefore a better estimator of the underlying noise processes. Detailed definitions of MTIE and TDEV are provided in ITU-T Recommendation G.810.[1]

Figure 9
Frequency accuracy.

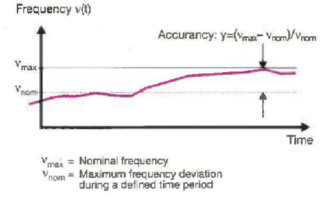


Figure 10
Ideal timing signal (a) and signal affected with Jitter (b).

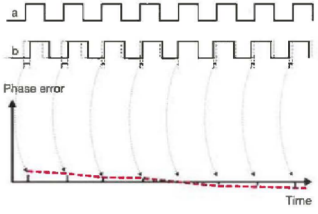
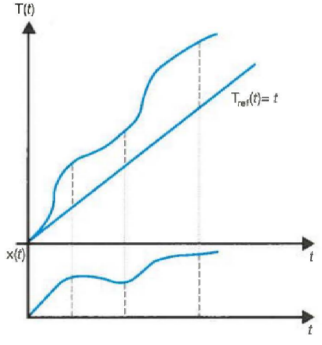


Figure 11
Example of time error.



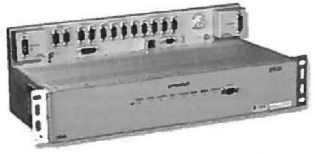


Figure 12
Photograph of a GPS system clock (GSC).

- to distribute frequency reference signals to telecommunications equipment;
- to distribute time-of-day (ToD) to telecommunications equipment;
- to retain highly stable holdover frequencies via a Rubidium oscillator; and
- to protect critical functions, including inputs, oscillators and outputs.

The CBC has an integrated GPS receiver and six inputs that terminate synchronization references carried by traffic links or dedicated synchronization references. The unit supervises every input, choosing and filtering the preferred references. When a GPS signal is available, the CBC uses it as one of the reference inputs. In this mode, the output quality of the CBC reference clock (PRC) exceeds the requirements specified by ITU-T G.811. The GPS receiver is also used to provide time-of-day to any system that supports the network time protocol (NTP).

Operator benefits of the CBC

Where network synchronization is concerned, the CBC can be used as a cost-effective alternative to a Cesium atomic clock for the implementation of a PRC source. In terms of synchronization distribution, it is highly suited to main or core sites that require reliable, high-quality synchronization. It can synchronize up to 60 different network elements at a site via output signals protected by hardware.

To guarantee proper handling, installation and operation, the CBC has been pre-configured and tested with AXE and CPP. The CBC provides numerous improvements for network elements co-located with it, and in general, improves overall network performance. For example, it

- provides a synchronization solution that caters for evolving networks;
- maintains a stable 14-day holdover frequency according to ITU-T G.811;
- improves the filtering of the incoming synchronization reference signal;
- improves the supervision of incoming reference signals (by means of parameters, such as MTIE and TDEV);
- distributes reliable synchronization reference signals to other equipment located at the site;
- provides full synchronization status message (SSM) support;
- provides full simple network management protocol (SNMP) support; and
- is fully supported by ITU-T-compliant synchronization element manager systems (EMS)—these can be provided with or without a northbound SNMP interface.

When locked onto a GPS signal, the CBC also

- supplies synchronization reference signals that are compliant with ITU-T G.811 (long-term accuracy comparable to UTC);
- flattens the synchronization distribution hierarchy;
- improves the reliability of the synchronization network;
- minimizes the overall costs of O&M, administration, and provisioning associated with the synchronization network; and
- provides accurate (Stratum 1) time synchronization via NTP over Ethernet.

CBC configurations

Ericsson's CBC is available in four configurations (Table 2). Each configuration addresses a specific market and application. Ordinarily, the CBC-E and CBC-A are installed in main sites where a large number of network elements needs to be synchronized to meet tough reliability and supervision requirements. The CBC-SE and CBC-SA are two cost-effective versions that can be installed in main sites where a smaller number of network elements needs to be synchronized to maintain reliability, functionality and supervision.

TABLE 2. SUMMARY OF THE MAIN CHARACTERISTICS OF AND DIFFERENCES BETWEEN THE FOUR CBC CONFIGURATIONS

CBC Version	Inputs	Oscillators	Outputs
CBC-E:			
CBC ETSI version	6 x E1 or Analog + GPS	2xRubidium	20 (1+1 protected) E1 + 40 (1+1 protected) 2048 kHz
CBC-A:			
CBC ANSI version	6 x DS1 or Analog + GPS	2xRubidium	20 (1+1 protected) CC + 40 (1+1 protected) DS1
CBC-SE:			
CBC for small sites, ETSI version	3 x E1 or Analog + GPS	1 Rubidium + 1 Quartz	20 (1+1 protected) 2048 kHz
CBC-SA:			
CBC for small sites, ANSI version	3 x DS1 or Analog + GPS	1 Rubidium + 1 Quartz	20 (1+1 protected) DS1

TABLE 3. MAIN BENEFITS TO NETWORK ELEMENTS CO-LOCATED WITH THE GSC

- Supplies synchronization reference signals that are in compliance with ITU-T G.811 (long-term accuracy comparable to UTC).
- Stable, 14-day holdover frequency (ITU-T G.811).
- Distribution of reliable synchronization reference signals to other equipment located at the site.
- Flattens out the synchronization distribution hierarchy.
- Improves the reliability of the synchronization network.
- Provides accurate (Stratum 1) time synchronization via SNTP and Ethernet.
- Facilitates inserting synchronization status messages (SSM) into outgoing framed signals (1544 and 2048 kpbs).
- Is fully supported by ITU-T-compliant synchronization EMS—these may be provided with or without a northbound SNMP interface.

BOX E, CBC TECHNICAL CHARACTERISTICS

Characteristics	Specifications
System	
Architecture	2 clock modules 1 communications module 1 or 2 input modules + GPS receiver 2 or 6 output modules
Chassis dimensions (H x W x D)	495 x 432 x 245 mm (fits in BYB 501)
Power connections	2 inputs (-48/60 vDC nominal)
EMC	Fulfills all EMC class-B standards
Input	
Number of inputs	Up to 6 + GPS
Supported interfaces	1 MHz 1.544 MHz 2048 kHz (ITU-T Rec. G.703) 5 MHz 10 MHz E1 (2048 kbps, ITU-T Rec. G.703) DS1 (1544 kbps, ITU-T Rec. G.703)
SSM	Compliant with SSM specifications T1X1.3 TR33, (ANSI) T1.101-1999; Telcordia Technologies GR-253 and 378-CORE; and applicable parts of ITU-T G.781
Clock	
Rubidium oscillator, compliance with international standards	ANSI T1.101 Stratum 2 and ITU-T Rec. G.812 type I/II
Quartz compliance with international standards	ANSI T1.101 Stratum 3E and ITU-T Rec. G.812 type III
Output	
Number of outputs	Up to 60
Supported interfaces	2048 kHz (ITU-T Rec. G.703) E1 (2048 kbps, ITU-T Rec. G.703) DS1 (1544 kbps, ITU-T Rec. G.703) 64+8 kHz composite clock (ANSI T1.101)
Wander output (MTIE and TDEV) CBC locked to GPS	Exceeds ANSI T1.101 PRS and ITU-T Rec. G.811
Wander output (MTIE and TDEV) CBC not locked to GPS	Exceeds ITU-T Rec. G.812 Type I/II or Type III (depending on whether clock is Rubidium or Quartz)
Output jitter	Meets ANSI T1.101 PRS and ITU-T Rec. G.811
Communication	
Physical interfaces	3 RS-232 serial ports 1 Ethernet 10BaseT port (Telnet, NTP, SNMP)
Management protocols	Interactive control set (ICS) Transaction language one (TL1) SNMP version 2
Time of day	NTP version 3 (RFC 1305)

GPS System Clock

The GSC is a cost-effective, stand-alone clock controlled by GPS. It is used for supplying network-frequency and time synchronization functions to telecommunications equipment (Figure 12).

Like the CBC, the GSC has been optimized for, but is not limited to, use with AXE and CPP. Its main functions are

- to distribute frequency reference signals to telecommunications equipment;
- to distribute time-of-day to telecommunications equipment; and
- to provide a highly stable holdover frequency via a Rubidium oscillator.

The GSC uses a GPS receiver to acquire a reference frequency of the system clock. The internal system clock, in turn, generates a reference signal for all outgoing reference signals.

When a GPS signal is available, the GSC delivers primary reference clock outputs whose long-term stability exceeds the requirements specified by ITU G.811. GPS is also used to provide time-of-day in SNTP format to any system that supports the network time protocol.[7]

Operator benefits of the GSC

The GSC is suitable for use in small sites that require reliable and high-quality synchronization. It can be used to synchronize up to 10 different network elements at a site. Where network synchronization is concerned, it can be used as a cost-effective GPS-based alternative to Cesium atomic clocks for the implementation of a PRC source. It can thus serve as a backup source or as a PRC for smaller sites.

The GSC has been pre-configured and tested together with AXE and CPP to guarantee proper functionality, handling and installation. Table 3 lists the main benefits of the GSC to network elements co-located with it, and general benefits to overall network performance.

The CBC and GSC in the network

As mentioned above, international standards recommend that stand-alone clocks

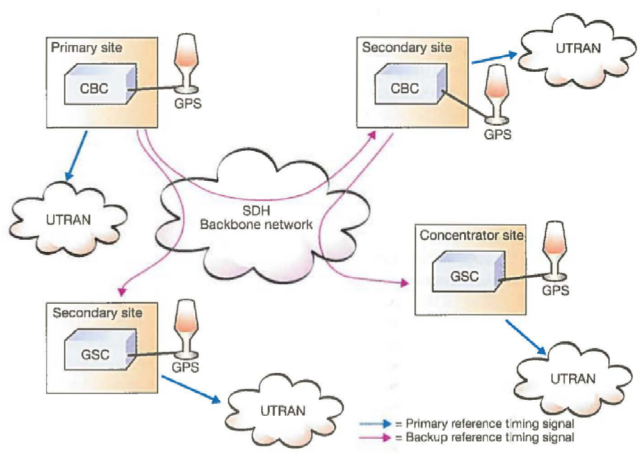


Figure 13
CBC and GSC application in the Mobile-PBN

BOX F, GSC TECHNICAL DESCRIPTION

Characteristics	Specifications
System	
Chassis dimensions (H x W x D)	150 x 432 x 213 mm (fits in BYB 501)
Power connections	2 inputs (-48/60 vDC nominal)
EMC	Fulfills all EMC class-B standards
Input	
Number and type	1 x GPS
System clock	
Rubidium compliance with international standards	ANSI T1.101 Stratum 2 and ITU-T Rec. G.812 Type I/II
Outputs	
Number of outputs	10
Supported interfaces	2048 kHz (ITU-T Rec. G.703) E1 (2048 kbps, ITU-T Rec. G.703) DS1 (1544 kbps, ITU-T Rec. G.703)
Wander output (MTIE and TDEV) GSC locked to GPS	Exceeds ANSI T1.101 PRS and ITU-T Rec. G.811
Wander output (MTIE and TDEV) GSC not locked to GPS	Exceeds ITU-T Rec. G.812 Type I/II
Output jitter	Meets ANSI T1.101 PRS and ITU-T Rec. G.811
Communication	
Physical interfaces	2 RS-232 serial ports 1 Ethernet 10BaseT port (Telnet, SNTP)
Management protocols	Interactive control set (ICS) Transaction language one (TL1)
Time of day	SNTP, version 3 (RFC 1769)

should be used to concentrate the synchronization functionality into one piece of equipment. In addition, by means of a GPS reference, the synchronization network can be planned using distributed PRCs to avoid having long synchronization distribution chains. The set of stand-alone synchronization products available in the Ericsson Core Network portfolio is suitable for most typical applications—for instance, main sites and remote sites to which it might be difficult or impractical to distribute a reliable reference timing signal.

Figure 9 shows a typical application of the CBC and GSC in the network—the Mobile-PBN release 3.0, which defines a network model based on different types of network. The illustrated network shows Primary, Secondary and Concentrator sites, which are the most meaningful types of site making up a network. The sites are interconnected via specific transport modules. The Primary sites are the core sites of the network—that is, they are the most important central sites, connected in a full mesh structure. They include transport, distribution, and access functionalities. The Secondary sites, which implement distribution and access functions, are redundantly connected to two Primary sites and possibly to a number of access sites. The Concentrator sites basically

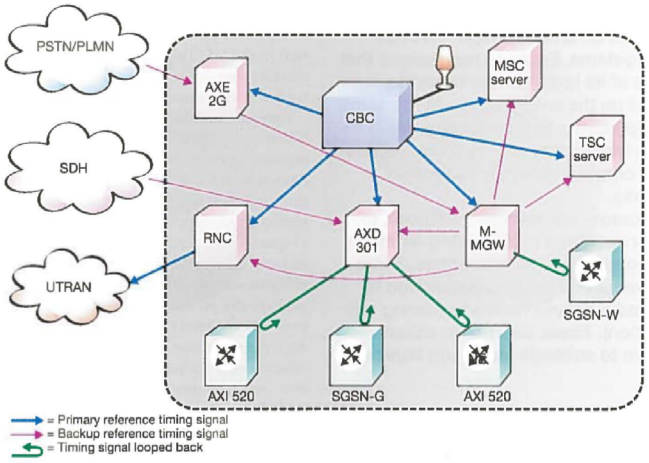


Figure 14
Example of intra-site synchronization in a Mobile-PBN primary site.

implement access functions. They are redundantly connected to one Primary and one Secondary site.

Mobile-PBN release 3.0 employs a distributed PRC architecture that implements the CBC concept at every main site. The importance of the Primary sites necessitates a robust, reliable and redundant source of synchronization. Therefore, in compliance with the distributed PRC approach, it is recommended that a CBC should be used at each Primary site. Figure 14 shows an example of intra-site distribution of synchronization in a primary site.

Secondary sites are smaller than Primary sites. Depending on their role in the network they could be candidates for a simpler clock, such as a GSC.

The CBC configuration is based on site characteristics, such as number of requested reference timing signals and market application (ETSI or ANSI).

Concentrators are the simplest types of site defined in the Mobile-PBN reference network model. They implement core transport capabilities and GSM/GPRS/WCDMA access. The GSC is suitable for this type of site.

Master-slave schemes can be used to provide backup references and to deliver suitable reference timing signals to access networks that are then slaved to the core network. The GSC might also be suitable in some UTRAN sites—for instance, to improve reliability and the quality of the synchronization reference.

Conclusion

A good synchronization network is a fundamental prerequisite for correct operation of any telecommunications network. In particular, this applies to the most recent mobile technologies, such as WCDMA, and hybrid (circuit- and packet-switched) networks, such as those based on Ethernet technology.

By defining reference sites and networks that take into consideration all relevant synchronization requirements, Ericsson has efficiently resolved the difficulties of building complex sites with mixed technologies.

The synchronization products available in Ericsson's core network product portfolio—the CBC and GSC—enable operators to comply with international recommendations in the area of network synchronization, and provide support for frequency and time synchronization. These products give operators reliable and effective solutions for building a wide range of synchronization networks.

REFERENCES

1 ITU-T G.811, Timing characteristics of primary reference clocks
2 ANSI T1.101-1999, Synchronization Interface standard
3 ETSI EG 201 793, Synchronization Network Engineering Guidelines,
4 RFC 1305, Network time protocol (version 3)
5 ITU-T G.810, Definitions and terminology for synchronization networks
6 ITU-T G.812, Timing requirements of slave clocks suitable for use as node clocks in synchronization network
7 RFC 1769, Simple network time protocol

Energy efficiency enhancements in radio access networks

Tomas Edler and Susanne Lundberg

More users and a total increase in the use of Ericsson's telecommunications systems are putting greater demands on energy usage. Through extensive life-cycle assessments of its systems, Ericsson has learned that energy consumption in the usage phase of its radio access networks is the most critical factor relating to impact on the environment. At the same time, operators are becoming increasingly aware of their energy bills. Consequently, Ericsson is committed to developing solutions that reduce operating costs and effects on the environment. How? By increasing energy efficiency in radio access networks.

Taking the customer perspective, Ericsson has used site, network, climate, and traffic statistics from operator networks to accurately estimate enhancements to energy consumption in real network operations. Examples of product enhancements include reduced energy consumption in RBS equipment, climate systems, and radio access networks (during roll-out) and legacy networks (during operation). These short-term enhancements are part of Ericsson's commitment to strategic long-term improvements.

Background

In recent years, the Information and Communication Technology (ICT) industry has actively participated in public discussions about energy consumption in terms of the industry's role as a large consumer, and solutions for reducing impact on the environment from transports and other energy-consuming activities.

Rising usage and new product and service launches have undoubtedly increased energy consumption, while new technologies have improved energy efficiency (Figures 1 and 2). In 2001, commercial office and telecommunications equipment represented less than 3% of all electricity consumption in the US. Telecommunications represented about 7% of this figure or 0.21% of total electricity consumption.[1]

Compared to the first generation of mobile systems, the energy efficiency of today's sophisticated multimedia systems has increased significantly (Figure 3). Given the growing number of ubiquitous services and applications, opportunities abound for participants in the telecommunications market to function as enablers of a more resource-efficient society. When used properly, the positive effects of ICT applications have the potential to greatly outpace increases in energy consumption. Therefore, Ericsson is continuously striving to make its radio access networks more energy-efficient. Likewise, Ericsson recognizes and supports its customers' efforts to improve the energy efficiency of their systems.

Environmental performance

Since the mid-1990s, Ericsson has conducted several extensive life-cycle assessments (LCA) that cover different aspects of telecommunications systems—for example,

- radio access network (RAN) products;
- core network products; and
- activities associated with operating telecommunications systems.

The LCA results point to one thing: the most significant environmental impacts from Ericsson's systems are associated with energy consumption during their use. Radio base stations are the single largest consumers of energy. Consequently, measures taken to reduce this consumption can directly benefit society.

Scope, design, and limitations of the LCA

Ericsson's most recent system-level LCA investigated a pilot UMTS network for 1.5 million subscribers during one year of operation. The pilot system consisted of

- 3G terminals (for example, mobile phones) and other advanced terminals;
- a radio network with radio base stations;
- radio network control equipment;

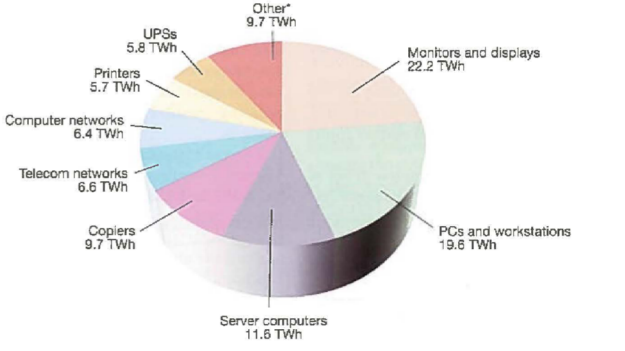


Figure 1
Electricity consumption attributed to information and communication technology in the USA (2001).

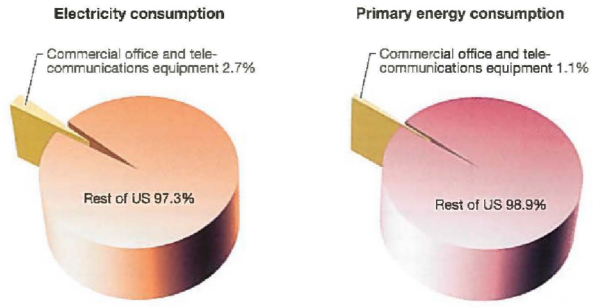

Electricity consumption
Commercial office and telecommunications equipment 2.7%
Rest of US 97.3%
Primary energy consumption
Commercial office and telecommunications equipment 1.1%
Rest of US 98.9%

Figure 2
Commercial office and telecommunications equipment represents less than 3% of the total electricity consumption (USA).

BOX A, TERMS AND ABBREVIATIONS

AC	Alternating current
BSC	Base station controller
BTS	Broadband telephony softswitch
CDF	Cumulative distribution function
DC	Direct current
EoL	End of life
GSM	Global system for mobile communication
ICT	Information and Communication Technology
LCA	Life-cycle assessment
PDF	Probability density function
RAN	Radio access network
RBS	Radio base station
RF	Radio frequency
RNC	Radio network controller
UE	Useful entity
UMTS	Universal mobile telecommunications system
WCDMA	Wideband code-division multiple access

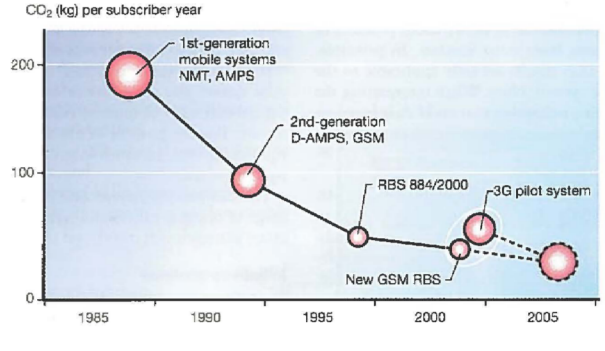


Figure 3
Ericsson is continually striving to make its radio access networks more energy-efficient.

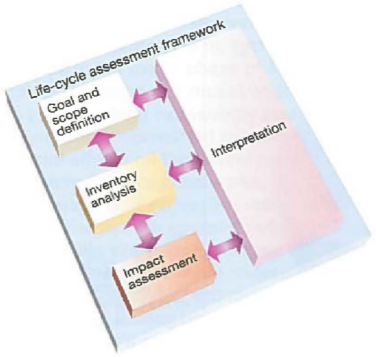


Figure 4
Life-cycle assessment methodology.

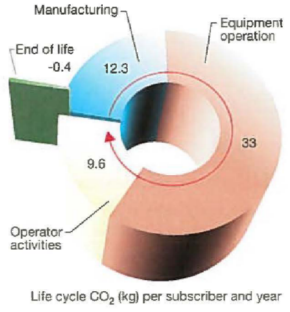


Figure 5
Environmental impact of the phases in the life-cycle of the 3G pilot system.

- a core network with switches, routers, servers, and workstations;
- transmission equipment, such as feeders and cable;
- various site materials, such as antennas; and
- climate-control equipment and site housing.

Application networks (mainly servers) were not included in the assessment. During the LCA, no full-scale commercial third-generation system was in operation. Therefore, the pilot system was sized using data from Ericsson's business operations—for example, data on subscriber behavior and system usage enabled the formulation of assumptions and predictions. Because the LCA only includes Ericsson equipment, no conclusions can be drawn about products or systems from other vendors. In principle, the LCA results are only applicable to the pilot system. Note: When interpreting the results, remember that an LCA is based on models that are simplifications of reality (Figure 6).

Key indicators of effects on the environment

The LCA investigated several impact indicators, such as climate change, resource depletion, and acidification. An interesting, unforeseen result was the prevalence of electricity production in most environmental impact categories. Climate change, measured in carbon dioxide (CO_2) equivalents during the entire life cycle of a system, is the most widely accepted indicator.

System life-cycle phases

Figure 5 illustrates the manufacturing, operational, and end-of-life (EoL) phases of the pilot system.

Product manufacturing (especially of electronics in user terminals) is a crucial activity within the manufacturing phase. This phase accounts for about 22% of the impact on the environment.

The operational phase, which is the most critical phase, includes actual equipment operation and operator office activities. During this phase, equipment operation and office activities account for about 78% of the total impact on the environment. The operation of telecommunications equipment accounts for about 60%.

The end-of-life phase has a positive effect on the environment thanks to recycling.

Third-generation system units

The picture changes when the LCA results are re-analyzed in terms of the main units of the pilot system—RBS, user terminals, network equipment, and business operations. Figure 7 shows that the RBS site plays a key role concerning impact on the environment. This is not surprising because a radio access network (valid for all systems—NMT, GSM, CDMA2000, etc.) consists of many RBS sites. The RBSs, which are connected to user terminals via the air interface, must be constantly prepared to deliver services to the 1.5 million users.

Manufacturing of user terminals affects the environment more than operation, because terminals have shorter commercial life cycles compared to other units in the network. And user terminals contain more electronic components (measured per weight and user) than all other network equipment.

Besides the aforementioned units, the pilot system also comprises other network equipment, such as routers, switches, and servers. For the purpose of the LCA, this equipment was grouped into a network equipment unit.

The business operations unit covers the usage of operator offices and facilities, real estate management, travel, and transports.

Initiatives continue

The LCA project created a unique model for telecommunications and an extensive database that contains information on materials, weight, energy consumption, and manufacturing procedures for every product in the pilot system. Ericsson intends to use these results

- to investigate and improve the way in which its products perform in terms of impact on the environment; and
- to cooperate with customers in future initiatives.

Improving energy efficiency in field networks

As stated above, the electrical power consumption of radio access networks has a real and important impact on the environment and costs. Below, we will discuss opportunities and methods for reducing energy consumption. To improve energy efficiency in field networks, Ericsson must understand

- network performance—that is, the amount of power consumed in different parts of the network;
- the relationship between climate and power consumption;
- how energy efficiency is measured in the network; and
- the potential of future technology.

In addition, Ericsson must set measurable objectives for short- and long-term enhancements.

Field network modeling

Ericsson gained extensive field experience from the estimations that came out of LCAs

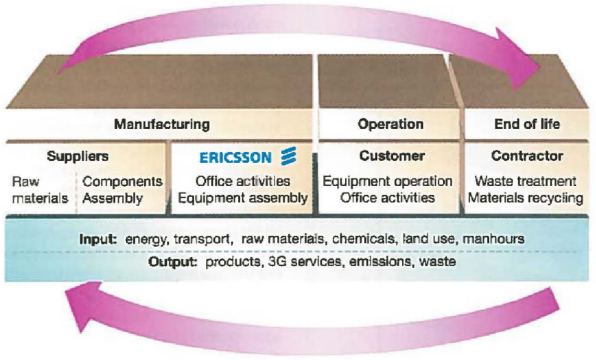


Figure 6
LCA of a 3G telecommunications system.

BOX B, LIFE-CYCLE ASSESSMENT METHODOLOGY

Life cycle assessments (LCA) evaluate the potential impact that a product or service might have on the environment (Figure 4). Products or services are studied from cradle to grave—that is, throughout their entire life cycles from raw material extraction to production, distribution, use, and disposal.

LCAs yield a set of impact indicators that represent local, regional, and global effects from the selected product or service. Examples of commonly used impact indicators are climate change, resource depletion, acidification, photochemical ozone generation, eutrophication, stratospheric ozone depletion, physical disruption of land, human toxicity, and ecosystem toxicity. Each LCA usually involves the following interactive phases:

1. Definition of goals and scope.
2. Inventory analysis of every activity associated with the product life cycle—data is gathered on energy usage, emissions, and waste treatment.
3. Environmental impact assessment through theoretical calculations.
4. Interpretation of results from inventory and impact assessment phases and synthesis of this information to draw conclusions.

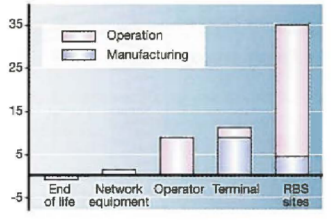


Figure 7
Environmental impact of sub-units of the pilot system.

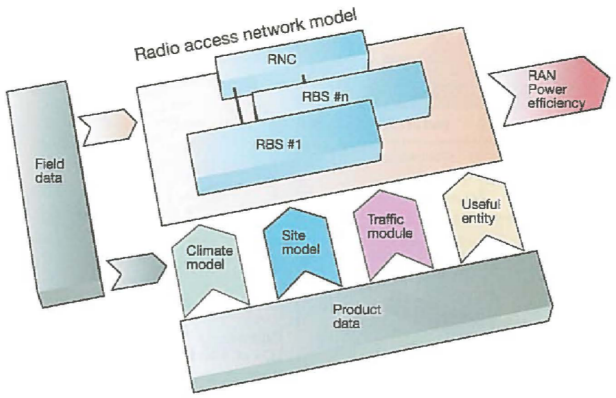


Figure 8
Key elements for estimating RAN power efficiency.

conducted in the mid-1990s when it gathered operational (site) and network data. Since then, Ericsson has developed a method for interpreting lab test data for its products—including all types of radio access network equipment—and for power consumption in the field. Estimations based on site equipment, such as air conditioners, also include equipment from other vendors.

Power consumption varies according to configuration, load, and environmental factors. Energy consumption (annual average power consumption) can be adequately estimated for field networks using several relevant models (Figure 8) for

- the WCDMA radio access network;
- site equipment;
- traffic load; and
- environmental temperatures.

When these conditions are known, it is possible to estimate RAN energy efficiency from product lab test data. After calculating the power efficiency of new products and even complete radio access networks, Ericsson can set goals and measure the extent to which the energy-saving requirements are fulfilled as new hardware and software are delivered and rolled out into the network.

Model network

Comparing networks is a challenging task. Ericsson uses a model network based on the most common RBS and broadband telephony softswitch products (BTS), and typical radio network controllers (RNC) and base station controllers (BSC).

The relationship between control nodes (RNC and BSC) and base stations reflects Ericsson's product offerings. The delivered mix of hardware is recalculated into delivery of model network parts. Because an RNC can handle more than 100 RBS nodes, the most significant consumption from the RBS and BTS nodes is in the radio access network. Therefore, energy-saving efforts must target RBS sites. The support of energy-saving radio network functions also affects the RNC and BSC nodes.

Site models

Energy consumption, or annual average power consumption, is estimated from an operator perspective under normal operating conditions. The power estimate includes the consumption of direct current (DC) by the RBS and the consumption of alternating current (AC) by rectifiers and climate equipment. Product data is used in the power estimate for Ericsson's outdoor RBSs. Field data, or key data from operator measurements, is used in the power estimate for climate and rectifier equipment from other vendors.

Approximately 2% of the AC input power at an RBS site is converted into radio frequency (RF) power to the antenna connector. Aside from rectifiers, the potential for improvement is substantial in every part at the site. If costs are disregarded, the total potential for improving power efficiency is 400%—that is, compared to a given output, it should be possible to reduce energy losses by 75%.

Climate models

A climate model is used to calculate the energy consumption of the climate system. Depending on power dissipation and the triggering temperature for different devices, such as fans, heat exchanger, and air conditioner, it is possible to calculate the portion of time during a year when various devices are used.

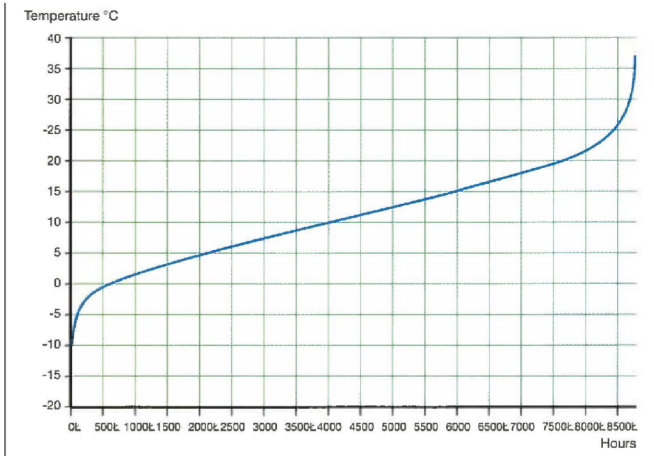
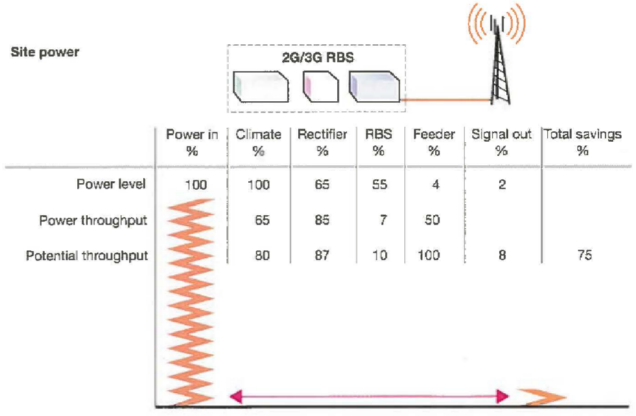


Figure 10
Central Europe climate model. Temperature given as a cumulative distributed function (CDF) over one year.

Figure 9
The RBS site model indicates current losses and potential for improvement.



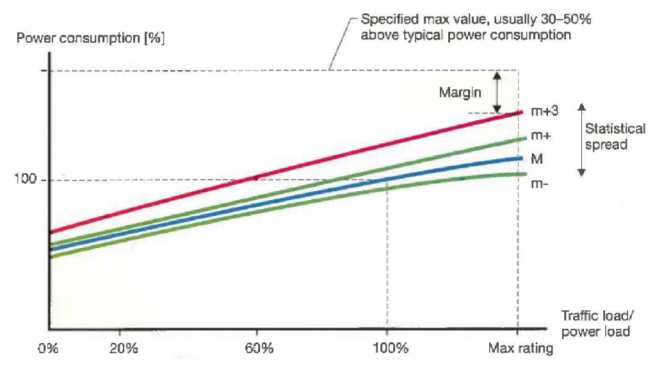
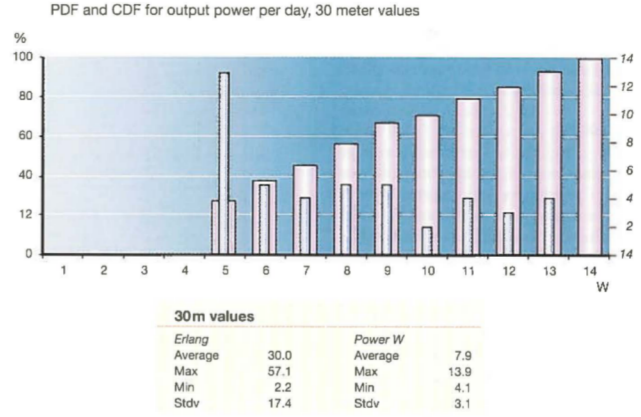


Figure 11
Schematic slide showing the impact of traffic load and product variations on power consumption.



30m values

Erlang		*Power W*	
Average	30.0	Average	7.9
Max	57.1	Max	13.9
Min	2.2	Min	4.1
Stdv	17.4	Stdv	3.1

Figure 12
Cumulative distributed function (CDF) for WCDMA power usage for the traffic model employed.

Traffic load and spreading factor

The power consumption of any node depends on traffic load and statistical spread. Average values are used. Spread is disregarded when estimating energy consumption. Load is determined by a traffic model based on field traffic measurements. When idle, the minimum load of the WCDMA pilot signal is 20% of nominal power. Admission- and congestion-control parameter settings limit maximum power. Nominal power, which can solely be reached during short intervals, averages 50-60% during busy intervals.

Figure 12 shows the WCDMA traffic model. A similar model has been developed for GSM. Power consumption in the WCDMA model has a basically linear dependency on traffic—that is, the 24-hour average value or 39.5% of nominal RF output power can be used to calculate average power consumption. The same can be said for CDMA2000, because WCDMA and CDMA2000 behave similarly in this regard. Power consumption in the GSM model is not linear (GSM uses several transceivers), and several steps must be integrated into the calculation to achieve correct results.

BOX C, POWER EFFICIENCY AND USEFUL ENTITY

Power consumption is measured as specific power consumption—that is, compared to the useful output capacity of nodes in the radio access network. The useful entity for RAN equipment in second- and third-generation systems is the product of coverage and capacity (voice equivalents). RF power efficiency of the site is the most important factor for achieving high power efficiency.
Useful entity (UE) = Coverage x Capacity

Potential solutions

Below follows some potential improvements to second- and third-generation RBS hardware and software. The improvements include climate and rectifier equipment on site, and the application of traffic and climate models. The reference site is an indoor site equipped with

- rectifier and climate equipment chosen by the operator; and
- indoor RBS.

Figure 13 shows that the RBS has a 30% potential for improvement. An even greater potential exists for the climate system and feeder. Realization of this potential is related to design—some solutions will require major redesign that is too expensive to pay off.

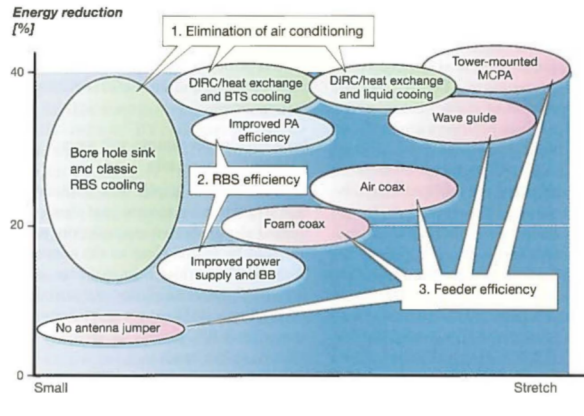


Figure 13
Potential for improvement—RBS site energy consumption.

A bore hole sink, used by a Swedish operator, is a relatively simple solution that offers efficient cooling. In temperate climates, this is a cost-effective solution. A combination of heat exchanger and air conditioner, which is used in GSM, CDMA2000 and WCDMA outdoor cabinets, cuts down on energy usage because the air conditioner must only operate when temperatures are high.

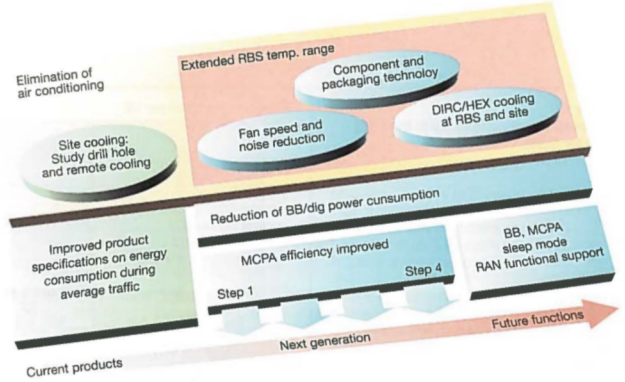
Heat transfer at the RBS, from transistor chip to cooling air, can be improved to the extent that air conditioning can be omitted. In most climates, heat-exchange cooling is sufficient. Liquid cooling and thermally improved transistor packaging are other examples of enhanced cooling.

Ericsson's goal to offer greater performance from a smaller footprint requires improved energy efficiency, because power loss is the most important factor for physical volume. The greatest losses occur during RF amplification and combination, and can be reduced by using more sophisticated amplifiers. The digital parts are being improved continually, which results in reduced consumption and greater functionality.

The use of different feeders—from thick, foam-insulated cables to wave guides—can reduce feeder losses of, say, 50% of RF power to just 7% of RF power. This change introduces a dramatic increase in weight and cost but does not affect the RBS design.

To eliminate practically all feeder losses, RF amplifier parts can be located at the tower close to the antenna. Examples of such products are the GSM Maxite RBS, with active antenna, the WCDMA main-remote RBS, and the CDMA2000 RBS 1127.

Figure 14
Solutions for improving energy efficiency at WCDMA RBS sites.


Elimination of air conditioning
Extended RBS temp. range
Component and packaging technology
DIRC/HEX cooling at RBS and site
Site cooling: Study drill hole and remote cooling
Fan speed and noise reduction
Reduction of BB/dig power cunsumption
Improved product specifications on energy consumption during average traffic
MCPA efficiency improved
Step 1
Step 4
BB, MCPA sleep mode RAN functional support
Current products
Next generation
Future functions

Potential problems

One problem with heat exchangers is that the cooling air is 5-10°C above the environmental temperature. Direct cooling solves the problem of rising temperatures but is susceptible to problems arising from dust, moisture and corrosive gases. Energy is saved, but a filter is required. If the filter is not designed to last the full operating lifetime of the equipment it serves, then the operator must make allowances for additional maintenance expense.

The drawback of current solutions that employ maintenance-free micro-pore filters is that corrosive gases are not filtered. Pressure increases over the filter will thus increase 800-1000% during its lifetime. Powerful fans are needed that are noisy and will consume excessive electric power. A sophisticated regulation system can reduce these problems, but at present, Ericsson is not satisfied with this technology.

Success stories

GSM macro base solution reduces energy consumption by 35%

The RBS 2206 for GSM, which succeeds the RBS 2202, was designed specifically to maximize traffic capacity and RF power on a limited footprint. Reducing power losses was not the primary goal of designing the RBS 2206, but by optimizing internal cabling, digital parts and RF parts, Ericsson improved power efficiency by about 50% at minimum load and close to 35% during normal operation.

New RBS main remote will save 13MWh/year per site

The new RBS is a split unit with a main, central part and a remote part that can be located elsewhere. For example, the remote unit can be placed close to the antenna to eliminate feeder losses. In that case, a half-size, 10W power amplifier unit will do the same job as a 20W power amplifier unit in a regular RBS, thanks to virtually non-existent feeder losses.

New macro base outdoor solution reduces energy consumption by nearly 20%

The most common type of site is an indoor site location with air conditioning. This is also the worst type of site in terms of environmental considerations, because the heat generated indoors must be evacuated using an air conditioner, adding about 50-65% to the energy consumption of the indoor RBS. The outdoor shelter for GSM, CDMA2000 and WCDMA uses a more sophisticated solution that combines air conditioning with heat-exchanger cooling. Depending on the RBS configuration, this solution reduces power consumption by 10-20%.

Software features cut power consumption 10-30%

The GSM downlink power-control function typically reduces RF output power by 3-5dB, which cuts RBS 2206 power consumption by 25-30%. The function has been on the market for some time but some operators are not using it yet. WCDMA and CDMA2000 have very efficient power control.

A new function for fan control in WCDMA RBSs cuts power consumption by up to 10%. This reduction is even greater where environmental temperatures are low and at sites with small RBS configurations.

Conclusion

Greater usage and new launches of telecommunications products and services have led to increased energy consumption. When used properly, however, the positive effects of applications from the ICT industry have the potential to greatly outpace increases in energy consumption.

Ericsson has conducted several extensive life-cycle assessments of its systems. The results of these assessments all point to one thing: the most significant environmental impacts are associated with operations, and radio base stations are the single largest consumers of energy.

With this information in hand, Ericsson is doing its part to make its systems more energy-efficient.

This article describes the scope, design and limitations of Ericsson's most recent system-level LCA of a pilot UMTS network for 1.5 million subscribers during one year of operation. The LCA looked at the various phases of the system life cycle. A key indicator of effects on the environment is climate change, measured in CO_2 equivalents.

Using data from the LCA, Ericsson developed a method for interpreting lab test data for its products and for power consumption in the field. The method consists of a field networking model, a model network, site models and climate models. It also considers traffic load and spreading factors.

Armed with real data from the LCA and a method for interpreting lab test data, Ericsson began enhancing the energy efficiency of its products—starting with the radio access network, where energy consumption is highest and has the greatest impact on the environment. Examples of new products with enhanced energy efficiency include the RBS 2206, a new RBS main remote, a new macro base outdoor solution, and software features that cut power consumption.

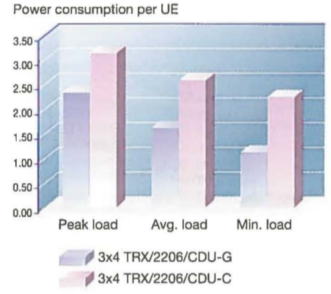


Figure 15
Improved energy efficiency in the RBS 2206 for GSM.

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The Public Ethernet—The next-generation broadband access network

Michael Begley

Thanks to its compatibility with IP, simplicity of deployment, and above all else, price-to-performance ratio, Ethernet is emerging as the leading standard for access technology. However, as currently deployed in the enterprise environment, Ethernet does not meet the requirements of a public telecommunications network. A broadband access network that carries real-time services must scale to handle large numbers of simultaneous users, offer excellent in-service performance, differentiate between services, and provide secure connections. Likewise, operators must have a management solution that helps them to roll out and maintain their networks and provide customer support.

This article describes Ericsson's Public Ethernet solution, which has been developed using standard Ethernet technology and incorporates the reliability, quality of service, security and manageability necessary for a public telecommunications network.

Broadband market trends

Telecommunications service providers are facing major changes in the services they provide and the infrastructure they use. In the broadband access market, some of the driving forces for these changes include

- demand for lower costs—the combination of a single service offering (high-speed Internet access) and relatively high access costs (especially in the backhaul connection) means that most operators are not yet generating sufficient revenue from their current broadband offering. Notwithstanding, to increase broadband penetration, they must lower their prices;
- increasingly complex home networks—the current broadband service offering (high-speed Internet access) is primarily intended for one PC per connection. But the emerging trend is for multiple devices per connection, such as two or more PCs, game consoles, and TV set-top boxes;
- new broadband applications—as broadband penetration increases and the market grows, the number of applications will also grow to meet the demand of increasingly technology-savvy users. Today's youth and professional early adopters, for instance, are driving the demand for the delivery of advanced applications, such as remote access, in-home health care, games on demand, and gambling;
- demand for greater bandwidth—advanced applications require greater bandwidth capacity, especially where multiple users share the connection. At present, applications such as online gaming account for nearly 9% of all backbone traffic in the USA, and as new services become available, end-users will indirectly demand greater bandwidth from the access network; and
- the need for service differentiation—the one-size-fits-all approach is not sustainable. Indeed, operators are already starting to differentiate service offerings with tiered bandwidth (512 kbps, 2 Mbps, 6 Mbps, and more). Ideally, the next step will be an access network that can deliver multiple services, such as a temporary bandwidth upgrade for, say, gaming or video conferencing.

For operators, the key to success in an increasingly competitive environment is to drive down the cost of delivering existing services and to open the door to new revenue-generating services. There are two aspects to delivering a cost-effective solution: scalability and cost (Figure 1). Ericsson's Ethernet DSL access node reduces costs substantially. Being uniquely scalable and making use of Ethernet technology, the IP DSLAM is a complete system on a board that facilitates expansion in steps of 10 or 12 subscribers at a time. The Ethernet DSL access node thus scales linearly to fit sites with as few as 10 subscribers to those with thousands of subscribers. As a backhaul link ("second-mile" transport), Ethernet is considerably cost-effective. The cost of an Ethernet uplink, for example, can be one-tenth that of an asynchronous transfer mode (ATM) uplink.

BOX A, TERMS AND ABBREVIATIONS

ADSL	Asymmetrical DSL
ARP	Address resolution protocol
ATM	Asynchronous transfer mode
BRAS	Broadband remote access server
CAPEX	Capital expenditure
CESoIP	Circuit emulation services over IP
CPE	Customer premises equipment
C-WDM	Coarse wavelength division multiplexing
DHCP	Dynamic host configuration protocol
DSL	Digital subscriber line
DSLAM	DSL access multiplexer
E1, E3	Digital circuit based on PDH (Europe)
EAPS	Ethernet automatic protection switching
EDA	Ethernet DSL access
FE	Fiber Ethernet
FEA	Fiber Ethernet access
FRoIP	Frame Rely over IP
Gbit	Gigabit
GE	Gbit Ethernet
ICMP	Internet control message protocol
IEEE	Institute of Electrical and Electronic Engineers
IGMP	Internet group message protocol
IP	Internet protocol
ISP	Internet service provider
ITU	International Telecommunication Union
Kbps	Kilobits per second
LAN	Local area network
MAC	Media access control
Mbps	Megabits per second
OC3	Optical carrier level 3
OSI	Open systems interconnection
OSS	Operations support system
PBX	Private branch exchange
PDH	Plesiochronous digital hierarchy
PIM	Protocol-independent multicast
PPP	Point-to-point protocol
PPPoA	PPP over ATM
PPPoE	PPP over Ethernet
PVC	Permanent virtual circuit
QoS	Quality of service
RADIUS	Remote authentication dial-in user service
RFC	Request for comments
RSTP	Rapid spanning tree protocol
SDH	Synchronous digital hierarchy
SLA	Service level agreement
SONET	Synchronous optical network
T1, T3	Digital circuit based on PDH (North America)
TDM	Time-division multiplexing
VLAN	Virtual LAN
VMAC	Virtual MAC
VoIP	Voice over IP
WAN	Wide area network
WDM	Wavelength division multiplexing

The Public Ethernet network

A public broadband access network must support traffic separation, service differentiation (quality of service), be secure, support multicast, be robust (in-service performance), and have a telecommunications management solution to support operation and maintenance of the network.

Traffic separation prevents end-users from eavesdropping the traffic of other end-users. It also separates services and other service provider traffic, giving the network operator full control of who talks to whom, thereby guaranteeing that only authenticated users may use network resources.

The definition of different classes of quality of service (QoS) makes it possible to differentiate between services—for example, those that are sensitive to delay and packet loss and those that are not. This ensures that the most sensitive applications and best-paying services receive priority when there is congestion in the network.

Although most end-users are genuine, a small percentage of them can be malicious. Therefore, to avoid fraud and service outage, operators must put security mechanisms in place to protect the network and other end-users.

Over the years, numerous experiments have been made to deliver broadcast services such as TV and radio over broadband networks. At present, the only cost-effective method of delivering broadcast services is multicast, where a single stream of data is transported through the network as close to end-users as possible and then duplicated and delivered to multiple end-users.

In-service performance is important to operators because network downtime results in lost revenue. Likewise, a resilient network is needed to fulfill service level agreements (SLA), avoid poor reputation and prevent customer churn.

Operators must have a comprehensive telecommunications management solution in place before they can build out infrastructure, provide services and effectively manage their networks. Present-day Ethernet-based local area networks (LAN) deployed in the enterprise environment cannot fully meet these requirements. Ericsson has thus designed and developed the Public Ethernet network solution (Figure 2).

Traffic separation

Originally, Ethernet LANs were based on coaxial cables, with each network device tapping into the cable. This resulted in poor performance and made it difficult to isolate faults. As Ethernet LANs continued to grow, the network devices were linked to a repeater (Ethernet hub) using twisted-pair wiring. In an Ethernet network built using hubs, only one device can transmit or receive data at a time and every device on the LAN must thus compete for available bandwidth. At best, this solution makes use of only 40% of available capacity.

To apply Ethernet on a larger scale, for example, in a wide area network (WAN) or Public Ethernet network, Ethernet switches replace the hub in the network. Ethernet switches examine packets, and process and

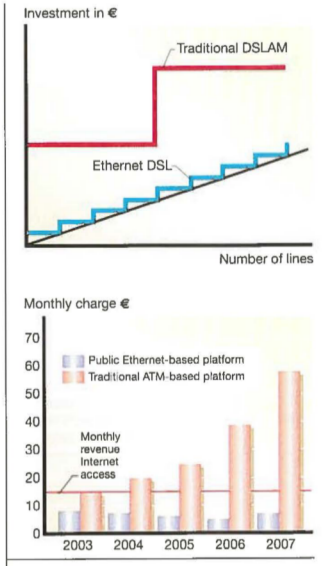
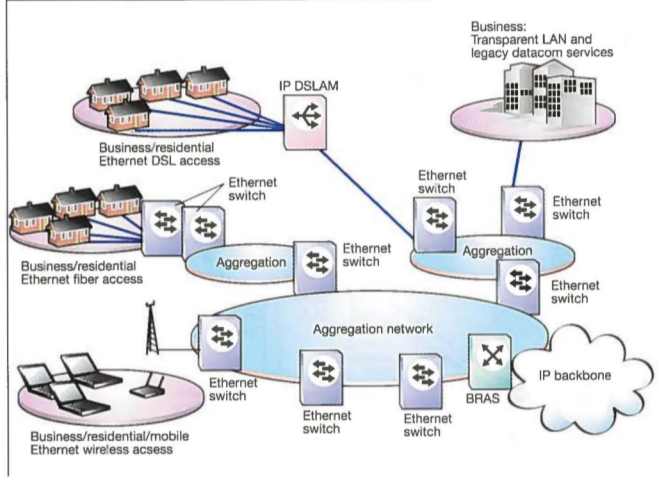


Figure 1
Overview of the scalability and cost competitiveness of the Public Ethernet network.

Figure 2
Overview of the Public Ethernet network.



prioritize them instead of simply repeating the signal to every port in the network. Switches map the Ethernet addresses of the nodes that reside on each network segment and only allow pertinent traffic to pass through them.

Ethernet switching thus facilitates a significant increase in bandwidth by enabling simultaneous switching of data packets between its ports, and segmenting the network into different broadcast domains.

A LAN is defined as a single broadcast domain. Therefore, when a user broadcasts information on the LAN, every user on the LAN receives the broadcast. The virtual LAN (VLAN) standard described in IEEE 802.1Q is an extension of the Ethernet standard that describes how a LAN can be logically segmented into different layer-2 broadcast domains. Because the segmentation is logical and not physical, end-users do not have to be at the same physical location.

For residential subscribers, VLANs are used to separate services into service VLANs. To prevent unauthorized access to the services, end-users are solely connected to the service VLANs to which they have subscribed (Figure 3).

End-users who access the same service VLAN are in fact connected to the same broadcast domain. In traditional LAN environments, the end-users would have layer-2 visibility—that is, their network devices would be able to communicate with one another on Ethernet layer 2. This gives rise to two main problems:

- End-users connected to the same service VLAN might establish direct peer-to-peer connections on layer 2, bypassing the service provider's broadband remote access server (BRAS), which controls access, provides security filters, manages charging, and allocates capacity.
- A malicious end-user might execute specific layer-2 attacks on other end-users.

Ericsson's Public Ethernet solution resolves these problems. Layer-2 visibility between end-user devices requires knowledge of a peer's layer-2 address, or media access control (MAC) address. Devices obtain the MAC address of other devices by broadcasting an address resolution protocol (ARP) request. To prevent this from occurring, and to direct all upstream traffic to the BRAS, the Ethernet access node implements the MAC forced-forwarding mechanism. An ARP proxy in the Ethernet access node prevents end-users from sending broadcast requests into the network by always responding with the MAC address of the BRAS. This ensures that end-user devices obtain the MAC address of the BRAS but not of other users. The upstream traffic of users who try to violate this rule is filtered out. All end-user traffic is thus forced to pass via the BRAS (Figure 4).

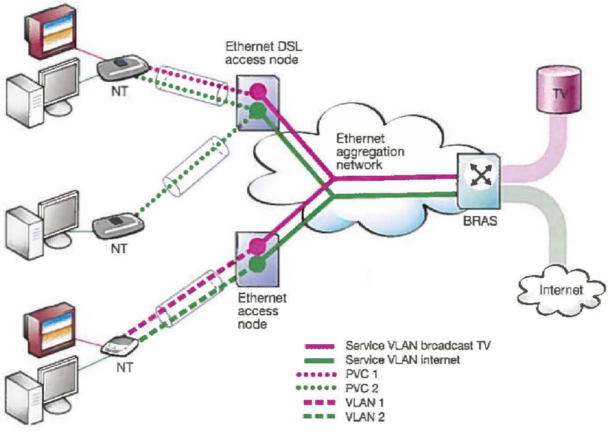
For point-to-point protocol (PPP) access, the PPP over Ethernet (PPPoE) protocol creates a tunnel between the end-user device and the BRAS. Each PPP tunnel is separated from other PPP tunnels, and because the Ethernet access node will only accept PPPoE frames, the upstream traffic can only flow to the BRAS. Therefore, no two end-users can obtain layer-2 visibility.

For business subscribers, a VLAN can be allocated to a specific end-user (the network of a branch, regional or corporate office) to create an isolated layer-2 network that can cross the IP core network in a layer-2 or layer-3 virtual private network (VPN). The traffic—which could be from a corporate intranet, circuit emulation services over IP (CESoIP) for PBX interconnection, or Frame Relay—is carried transparently through the layer-2 network (Figure 5).

Quality of service

IEEE 802.1p, which is part of the IEEE 802.1Q standard, defines the Ethernet priority bits used for QoS over Ethernet networks, stipulating eight levels of priority that can be assigned to a VLAN. If congestion develops in the network, the Ethernet switches first drop Ethernet frames marked with lower priority. Likewise, if bandwidth shaping or policing are applied, then it is possible to define a maximum and minimum bandwidth for the VLAN or end-user. Bandwidth shaping buffers traffic to compensate for traffic bursts, keeping traffic levels within the limits defined for the VLAN.

Figure 3
Overview of VLAN per service.



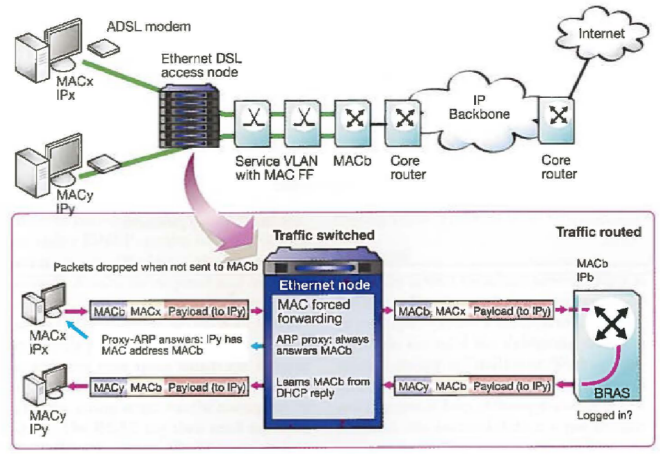


Figure 4
Overview of the service VLAN and MAC forced-forwarding mechanism.

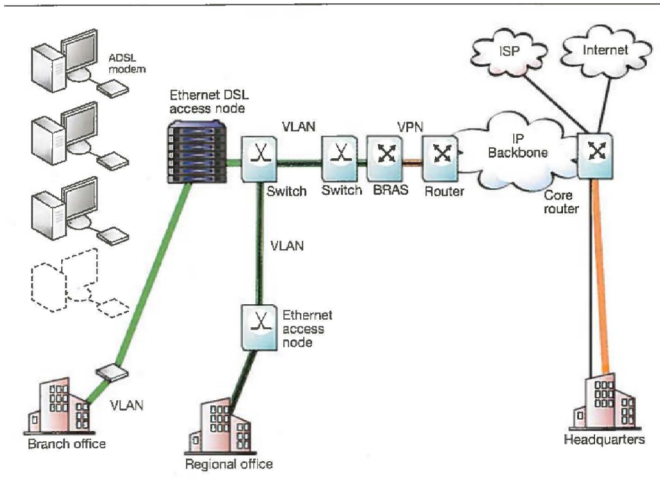


Figure 5
Overview of VLAN per customer and transparent connection.

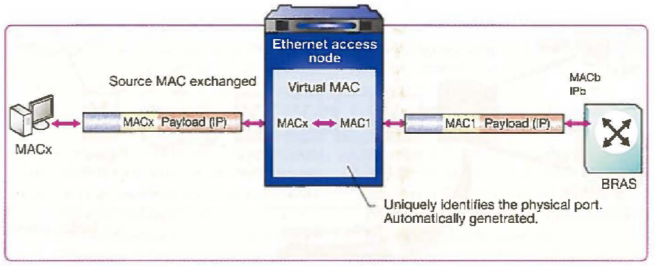


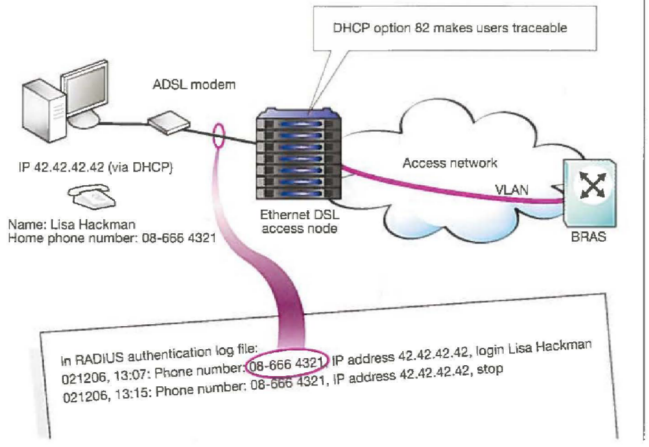
Figure 6
Overview of the virtual MAC address function.

The technique reduces traffic loss, but introduces delay and jitter into the traffic stream.

Bandwidth policing causes packets to be dropped as soon as the limit defined for the VLAN is reached. More traffic is lost, but traffic that does not exceed bandwidth limits experiences low delay and jitter. This is an attractive option for voice over IP (VoIP) and video traffic. In summary, a combination of IEEE 802.1p and bandwidth shaping or policing makes it possible to assign a QoS profile to a VLAN (the end-user's logical connection that carries the service).

When end-user traffic reaches the IP core network (the BRAS or edge router), the different IEEE 802.1p priorities are mapped into differential services (DiffServ) classes or multiprotocol label switching (MPLS) experimental bits to maintain the priority of the traffic as it is routed through the IP core network.

Figure 7
Overview of DHCP option 82.


DHCP option 82 makes users traceable
ADSL modem
IP 42.42.42.42 (via DHCP)
Name: Lisa Hackman
Home phone number: 08-666 4321
Ethernet DSL access node
Access network
VLAN
BRAS
In RADIUS authentication log file:
021206, 13:07: Phone number: 08-666 4321, IP address 42.42.42.42, login Lisa Hackman
021206, 13:15: Phone number: 08-666 4321, IP address 42.42.42.42, stop

Security

One method of identifying end-users who have accessed the network is to record their MAC addresses. However, this method has some fundamental drawbacks—for instance, it is difficult to trace a MAC address to a specific end-user, end-users can easily modify their MAC addresses, and multiple devices can appear in the Ethernet access network with identical MAC addresses, either intentionally (spoofing) or by accident.

To counter these problems, the Public Ethernet network solution makes use of virtual MAC addressing. In the Ethernet access node, the end-user MAC address is mapped to a unique, locally generated MAC address (virtual MAC). This is used within the access network as an alias for the end-user's MAC address. The algorithm used to generate the virtual MAC address identifies the port and logical connection to the end-user. Consequently, the virtual MAC address, which is outside the control of the end-user, can be used to identify the exact source of all upstream traffic. In addition, the function enables operators to protect the network from malicious end-users, by blocking their attempts to broadcast multiple MAC addresses into the network to overload the MAC address tables in the Ethernet switches (Figure 6).

Operators who use the dynamic host configuration protocol (DHCP) to assign IP addresses to end-users can enhance this function using DHCP option 82. When end-users request an IP address, the Ethernet access node detects the requests and modifies them by adding a string that identifies each end-user. The Ethernet access node can automatically generate this string to identify the end-user port from which the request originated. Alternatively, the operator can define the string to use via the management system. The BRAS can then send information such as time, date, IP address and identifier to the RADIUS log to keep a record of which end-users logged onto the network, and from which ports the end-user traffic originated. The operator can thus trace end-user activities if necessary (Figure 7).

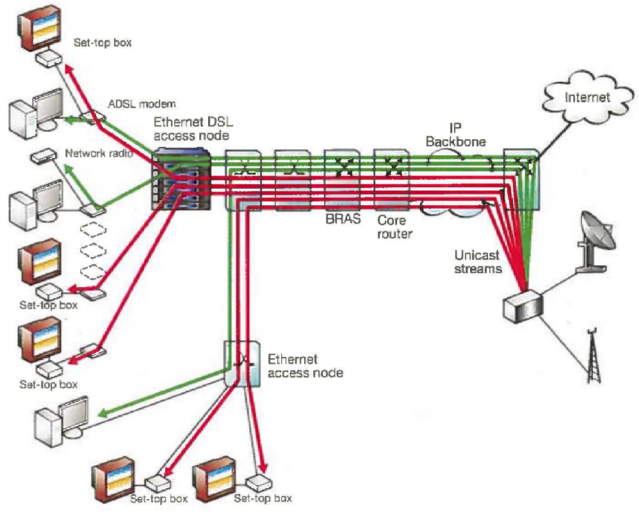
Filtering rules implemented in the Ethernet access node provide additional security. For instance, it is possible to set up rules for processing traffic on layer 2 or layer 3. To prevent IP spoofing,the Ethernet access node can be configured to solely accept traffic from the IP address or IP subnet assigned to the end-user. The Ethernet access node learns the assigned IP address or IP subnet by snooping the DHCP reply sent from the DHCP server. For end-users with a static IP address, it obtains them from the management system.

Multicast

There are several broadcast services, such as TV and radio, that send the same data stream to multiple end-users simultaneously. Two methods are used for delivering the data stream: unicast and multicast. With unicast, an end-user requests access to the data stream and it is sent to him. Although simple to implement, the unicast solution is not scalable because the same data must be sent 100 times to 100 different end-users (Figure 8).

With multicast, a single data stream is transported through the network as close to end-users as possible before it is duplicated and delivered. This approach saves bandwidth in the transport network and reduces load on the content server, providing a much

Figure 8
Overview of the unicast implementation.



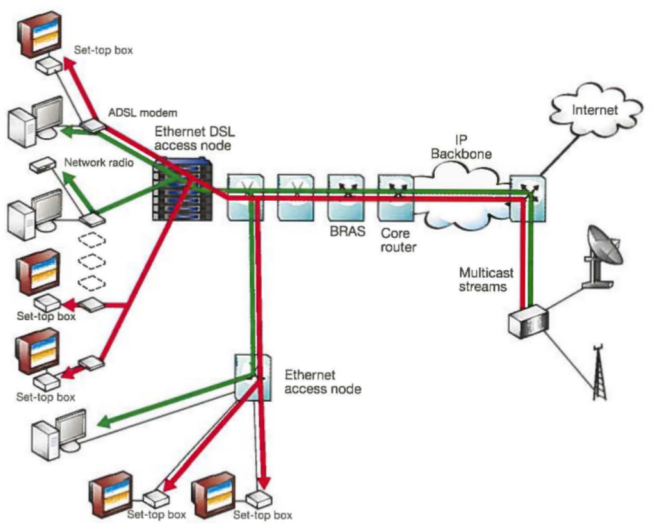


Figure 9
Overview of a multicast implementation.

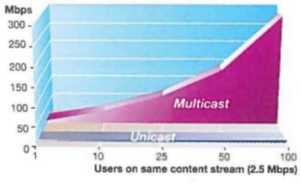


Figure 10
Unicast bandwidth increases uniformly with more users, whereas multicast bandwidth remains constant.

more scalable and cost-effective solution for delivering broadcast services (Figures 9 and 10).

For multicast to work, a protocol is used to determine the multicast group, so the router or switch can determine which traffic to forward to each end-user. The Public Ethernet network uses the Internet group management protocol (IGMPv2 RFC 2236). End-users send join and leave messages to tell the network which multicast session they want to participate in. The Ethernet DSL access nodes and Ethernet switches in the aggregation network snoop the IGMP requests to detect and maintain the multicast groups.

The Ethernet access node can also keep a "white list" of the IGMP groups to which a given end-user is allowed to access. Operators can thus set the end-user port on the Ethernet access node to restrict access of a specific end-user to, say, IGMP groups 1-20 (for example, TV channels 1 - 20 in a basic subscription package). The Ethernet access node blocks any attempts by end-users to select IGMP groups to which they do not have access.

Robustness and availability

To fulfill service level agreements, prevent customer churn, and avoid poor reputation, operators must have a resilient network. Equipment can feature internal redundant hardware—some equipment is fully redundant, some only partially redundant. Network redundancy, which protects against the failure of a link or network element, is achieved by having alternative paths for end-user traffic through the network.

The use of two fibers between Ethernet switches provides 1+1 physical link redundancy with two physical links to carry traffic between Ethernet switches and with failover time of less than 50 µs.

The solution also employs rapid spanning tree, a relatively lightweight protocol specified in IEEE 802.1w that enjoys wide support in the industry. The protocol makes it possible to redirect end-user traffic (typically within 5 seconds) via an alternative path when the primary path fails. It is a cost-effective redundancy option at the edge of the network (for example, at the Ethernet DSL access node) where nodes are often remotely placed with a small number of Ethernet switches, links and VLANs, and relatively few subscribers are affected by a single failure.

The Ethernet automatic protection switching (EAPS) protocol, specified in RFC 3619, works in networks built with a ring topology, where a master node redirects traffic in response to failure. EAPS has a failover time of less than 50 ms, providing the in-service performance required in the Ethernet aggregation network, where a single failure can affect a large number of users.

These redundancy mechanisms enable operators to build a Public Ethernet network with 99.999% availability.

Telecommunications management

Operators need to have a comprehensive telecommunications management solution in place before they can build out infrastructure, provide services, and effectively manage their networks. An element manager, called PEM, offers fault-management, configuration-management, performance-management and security-management functionality for managing the Ethernet access nodes.

Likewise, the Ethernet connection manager (ECM) is a tool for configuring VLANs and network resources end-to-end in the Public Ethernet network. It supports a wide range of network topologies and can be adapted to support equipment from a variety of vendors. The ECM collects a vast amount of data on the network and network topology in its database. This data also has a useful secondary value outside the ECM and can be used to assist operators in engineering traffic for network expansion and usage.

Finally Ericsson has a service offering to assist operators in rolling out and installing the Public Ethernet network as well as in integrating it into systems for service provisioning, network management, work practices and business support.

Transport solutions for the Public Ethernet network

Although the many advantages of Ethernet broadband access are compelling, operators with extensive ATM and synchronous digital hierarchy (SDH) transport networks must find a way of fully utilizing and migrating existing network architectures. This migration can be addressed in different ways, depending on the architecture and operator plans.

Ericsson offers a range of solutions that interface the Ethernet access network to legacy transport technologies, such as ATM, SDH and plesiochronous digital hierarchy (PDH). The product portfolio covers

- Ethernet over dark fiber;
- Ethernet over course wavelength division multiplexing (C-WDM);
- Ethernet over radio link—point-to-point or point-to-multipoint;
- Ethernet over SDH or PDH, either as E1/T1, E3/T3, or STM-1/OC3;
- Ethernet over the next-generation SDH network; and
- Ethernet over ATM.

Migration of traditional TDM- and ATM-based services to Public Ethernet

Although the Public Ethernet network opens up new and exciting opportunities, legacy applications based on E1 leased lines and Frame Relay connections will continue to exist. To cater for these applications, transparent LAN connections (VLAN) are created in the Ethernet access network, and equipment is placed at the subscriber's premises (customer premises equipment, CPE)—the CPE converts subscriber traffic to circuit-emulation services over IP (CESoIP, structured and unstructured) or Frame Relay over IP (FRoIP). These services are then carried transparently through the Public Ethernet network with high priority and minimum delay and jitter.

Conclusion

The continuing evolution of broadband access will create numerous challenges for service providers, who in an increasingly competitive environment must drive down the cost of delivering existing services and simultaneously open the door to new revenue-generating services.

Ericsson's Public Ethernet network solution has been designed and developed to meet these challenges. By drawing on standard Ethernet technology, Ericsson can offer a broadband access network with an unbeatable price-to-performance ratio, while maintaining the carrier-class functionality, security, quality of service and scalability of traditional telecommunications networks.

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